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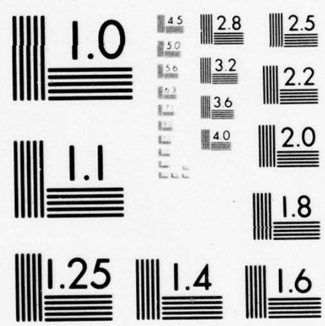
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TECHNICAL REPORT ARLCD-TR-78019

EVALUATION OF NEW BONDING SYSTEMS FOR DEPOT-LEVEL MAINTENANCE OF AIRCRAFT HONEYCOMB PANELS; FINAL REPORT

DECEMBER 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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Four adhesive systems, EA 9628, ADX 656.2, PL 717B, and M 1113, are evaluated and reported to be improvements over adhesives presently used for bonding honeycomb structures in army helicopters. These systems have increased durability and fatigue properties but do not change the stiffness of the panel. Using corrosion-inhibiting primers can increase the life expectancy of the structure provided the application of the primer is very stringently controled. An investigation into fracture

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analysis of failed joints indicates that the origin of failure, the mechanism of crack propagation, and an estimate of the load the joint experienced at the time of failure can be detected by a careful analysis of the joint. A nondestructive technique by which the degradation in a bonded panel can be followed using the Harmonic Bond Tester has been evaluated. The technique detects changes in the adhesive, the onset of corrosion in the bond line, and the presence of voids.

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INTRODUCTION

The Adhesives Section, Organic Materials Branch, Applied Sciences Division, Large Caliber Weapon Systems Laboratory, US Army Armament Research and Development Command, formerly the Adhesives and Coatings Branch, Materials Engineering Division, Feltman Research Laboratory, Picatinny Arsenal, has conducted an investigation of new bonding systems for depot-level maintenance of aircraft honeycomb structures. This report summarizes the findings reported in the first four reports (refs. 1 through 4) and details the findings related to the investigation by nondestructive inspection of degradation in a bonded joint and the evaluation of the effect of corrosion-inhibiting primers on the durability of adhesive-bonded joints.

DISCUSSION

Evaluation of Structural Adhesives

Previous investigations (refs. 5 through 8) have evaluated the manufacturing processes and adhesives used in helicopter manufacture and the adhesives and methods used for field repair of aircraft honeycomb structures (ref. 9). In this program we investigated newer 121°C curing structural adhesives for use in honeycomb structures. Our particular objective was to look for improved durability and reliability in the bonded structures.

The approach involved selecting the candidate adhesives, evaluating their physical properties, and evaluating the durability of the bonded joints. Based upon our findings, we selected the candidates for our followup investigation. This included evaluating their fatigue lives at room temperature, elevated temperature, elevated temperature and high humidity, and evaluating some processing variables such as bonding to anodized aluminum and etched titanium. This evaluation also investigated the effects of storage of the adhesive on the durability of subsequent bonds and the effects of out-time of the adhesive, the period of time the adhesive is out of the freezer before it is used, on the durability of the resultant bonds.

Physical Properties

Table 1 shows the physical properties of honeycomb panels which were tested using the climbing drum peel to determine peel resistance and the sandwich panel flexural test to determine stiffness. The data show that the four new adhesives, Metlbond 1113 (M1113), Hysol EA 9628, Hysol ADX 656.2, and Plastilock 717B (PL 717B) have higher peel resistances

than the control adhesive. The type of failure is cohesive for all the new adhesives, that is, adhesive was left on the skin and also on the cell edges.

The panel with M1113 adhesive had the same stiffness as the control adhesive. The others increased in stiffness over the M1113 panel in the following order: EA 9628, ADX 656.2 and PL 717B.

Durability Screening

A new test has been developed to screen a large number of variables such as adhesives, adherends and surface preparations. This test allows for a rapid prediction of the durability of the bonded joints. It involves soaking the specimens in hot water for prescribed periods and then testing the residual strength at 60°C while the specimen is still wet. Table 2 is a summary of the data obtained at room temperature and 60°C controls compared to the data obtained from the hot water soak/residual strength test. The data in table 2 show that the percent loss caused by heating the bond without soaking it is, in increasing order, EA 9628, ADX 656.2, M1113, and PL 717B. The percent residual strength lost after 1,000 hours water soak compared to the original room temperature strength is calculated and related to durability so that the lowest percent loss indicates the most durable joint. The expected durability in decreasing order is EA 9628, PL 717B, ADX 656.2, and M1113. Figure 1 compares the stress durability data obtained at 60°C and 95% relative humidity (RH) for the adhesives and the two control adhesives. The stress durability data was obtained in accordance with the Annual Book of ASTM Standards, Part 16 (ref. 10). The control adhesives are two of the adhesives now approved for use in bonding panels for many of the Army's helicopters. This figure shows that the four adhesives being investigated are more durable than the control adhesives. The EA 9628 and the PL 717B behave similarly to the Control A system and are more stress-sensitive than the ADX 656.2 and M1113 which behave similarly to the Control M. The long term low-stress-level durability ranking would be EA 9628, PL 717B, ADX 656.2 and M1113, respectively. This agrees with the order predicted from the hot-water soak data presented in table 2.

Stress Durability

The data presented in figure 1 were obtained using FPL-etched 2024-T3 aluminum adherends. However, many of our panels use either anodized aluminum skins or titanium skins. Figures 2 through 5 show a

comparison of the durability curves of the four adhesives on the three surfaces, with the curves of the two control adhesives on FPL-etched 2024-TE aluminum. For all three adherends the durability of the EA 9628 is much better than the controls (fig. 2). Figures 3 and 4 again show a significant increase in durability when the PL 717B and ADX 656.2 adhesives were used to bond the three adherends. Figure 5 shows the data obtained when the M1113 adhesive was used to bond the three adherends. Again the durability of these joints is superior to that of the control adhesives. The specimens prepared with the etched aluminum were prepared when the adhesive was four months old. Those prepared with the titanium and anodized aluminum were made when the adhesive was 14 months old. This could account for the lower values obtained from titanium and anodized aluminum. This is being substantiated by another program presently underway. The effects of adhesive age or storage life on durability will be discussed later in this paper.

Fatigue

By nature of its design a helicopter is a highly vibrated structure. The aircraft is suspended during flight from the rotating blades which are constantly changing pitch to pick up and dump loads. These actions cause vibrations to be set-up and transmitted throughout the structure. A helicopter flies at low levels so the operational environments are similar to the environments of the theater of operation. For example, in the Southeast Asia conflicts, the aircraft not only was exposed to high temperature and humidity on the ground but also during much of its flight time. Therefore, it was of interest to determine fatigue characteristics as a function of temperature and temperature plus high humidity.

Fatigue curves were obtained at 1,000 cycles per minute in a tension-tension mode, at 23°C with 50% RH, 60°C and 60°C with 95% RH. In general, the fatigue curves obtained at the three environments follow the trend shown in figure 6 where a noticeable drop is experienced when the environment is changed from 23°C to 60°C and again when the humidity is raised to 95% RH at 60°C.

The fatigue curves obtained for the four adhesives at 23°C are compared in figure 7 while those curves obtained at 60°C are shown in figure 8. In both test environments, the ADX 656.2, EA 9628, and M1113 showed very similar patterns; the PL 717B was lower. Table 1 shows that the PL 717B produced stiffer joints than the other three.

Figure 9 compares the fatigue curves obtained at 60°C and 95% RH. Under this, the harshest of the test environments, the four systems approach each other with respect to their fatigue resistances. Contrary to the general pattern described in figure 6, the PL 717B produced a range of fatigue curves which approached each other regardless of the environment (fig. 10).

Based upon these tests it would appear that even though the ADX 656.2, EA 9628 and M1113 adhesives fatigue curves at 23°C and 60°C are higher than those of the PL 717B, the environment of 60°C/95% RH acts as an equalizer and they all have similar fatigue patterns.

Storage Life and Out-Time

Since an adhesive film is generally used over a period of time it was desirable to determine the effects of cold (freezer) storage and out-time (that period of time the adhesive is out of the freezer before use) on the durability of joints made with the adhesive.

Lap-shear specimens were prepared each month with each of the four adhesives. The specimens were then tested at 60°C for control strengths. The specimens were immersed in 60°C water for 100 hours and 1,000 hours. They were removed from the water and tested immediately in a chamber maintained at 60°C.

The results of the storage-life study are shown graphically in figure 11 which shows the effect of -20°C storage of the adhesive on the durability of subsequent bonds. The general trends shown in this figure were also true for the control and 100-hour immersion but were most conclusive after 1,000 hours immersion.

Figure 11 shows that the PL 717B adhesive has a storage life of about 7 months; after that the durability of the bonds start to degrade.

Both the EA 9628 and the ADX 656.2 adhesives have storage lives of at least 13 months with no apparent detrimental effect upon the ability of the adhesive to form good durable joints. The M1113 adhesive shows a slight drop in the durability of the bonds made after the adhesive was about 9 months old.

Figure 12 depicts the durability as determined by the 1,000-hour hot water soak residual strength test as a function of out-time. The figure shows that the four adhesives can be removed from the freezer and stored at 23°C and 50% RH for at least 35 days. This was true for rolls of new adhesives and also for samples taken from rolls which had been aged in the freezer.

Observations

The four adhesive systems, EA 9628, ADX 656.2, PL 717B, and M1113 all appear to be improvements over the Control A and Control M adhesives. There are trade-offs between the different adhesive systems. For example, the PL 717B system was stiffest, had the highest peel resistance, and was one of the most durable, but it was the most sensitive to stress. The system also had the lowest fatigue curves but there was no substantial change in fatigue spectra due to environmental changes.

The other systems were not as stiff, were somewhat less resistant to peel, had higher fatigue curves which decreased as temperature and humidity increased, and were less sensitive to stress during sustained loads under adverse environments. They also had longer -20°C storage lives.

All four systems have an out-time at 23°C/50% RH of more than 35 days.

ANALYSIS OF FRACTURE OF ADHESIVE BONDED JOINTS FAILED IN FATIGUE

During the evaluation of the new bonding systems for depot maintenance of aircraft honeycomb structures, an analysis of fracture was conducted. The specific objective of this phase of the work was to establish whether a study of the surfaces of broken bonds could determine the mechanism of failure, the origin of the failure, and the load to which the specimen was subjected at the time of failure. The specimens used in this study were those obtained from the fatigue testing conducted in the earlier part of this program.

During this analysis of failure, the following observations were made (ref. 4):

1. The origin of the failure was located by studying the failed surfaces, especially in the vicinity of the adhesive fillet. It was found that small cracks originated from voids or gas bubbles in the surfaces of the fillet. These cracks progressed into the joint until the joint failed.

2. A careful examination and interpretation of the marks in the surface indicated the direction of crack propagation.

3. At low loads the fatigue failure mechanism in a hot, wet environment was by fracture of an oxide layer that formed between the adhesive and the metal substrate. This type of failure has also been noticed previously for long-term wet static failures.

4. In an ambient or a hot, dry environment, the mechanism of failure was cohesive failure of the adhesive. This was also the case at high load in a hot, wet environment for specimens which failed in a short time. Again, this phenomenon had been noticed for static, short-time durability failures.

5. It was possible in these specimens to estimate the load experienced by the bond at the time of failure. The shear area found in the failed joint was proportional to the failing load.

Detailed discussions of these observations can be found in reference 4.

EVALUATION OF THE EFFECT OF CORROSION-INHIBITING PRIMERS ON THE DURABILITY OF ADHESIVE BONDED JOINTS

In the first phases of this investigation, interest was primarily in evaluating adhesives in bonded joints. In this second phase, the investigation changed to evaluate the effect of the use of corrosion-resistant primers in combination with adhesives on the durability of adhesive bonded joints. The first part of the investigation of corrosion-resistant primers involved using the manufacturer's recommended corrosion-inhibiting adhesive primers (CIAP). Adherends were supplied by the Government and were treated, primed, and bonded by the adhesive manufacturers.

Four adhesive/primer systems were selected for this evaluation. These were: ADX 656.2/238.1, EA 9628/ADX 238.1, PL 717B/718-2 and M1113/6740. The four systems were selected on the basis of the performance of the adhesives without primer as determined during the first phases of this investigation.

Table 3 lists the durability data obtained at 60°C and 95% RH. The specimens were exposed to this environment under various stresses. A comparison of the data obtained at a stress level of 13.7 MPa (2000 psi) generally shows a substantial increase in the durability of the joints when

the adherends were primed with a corrosion-resistant primer. This observation is true for ADX 656.2, EA 9628, and PL 717B. However, data obtained with the M1113 adhesive show no significant change in durability at the 13.7 MPa stress level.

Figure 13 is a graphic comparison of the durability curves obtained with ADX 656.2 adhesive system with and without the use of ADX 238.1 primer. Figure 13 shows that the use of ADX 238.1 primer appears to substantially increase the durability of the bonded joints.

Figure 14 depicts the durability data obtained with the EA 9628 adhesive system with and without ADX 238.1 primer. Again, the data indicate a substantial increase in the durability of the joint when the ADX 238.1 primer is used.

Figure 15 graphically depicts the data obtained with the PL 717B adhesive with and without PL 718-2 primer. It shows that a significant increase in durability is obtained when the adherend is first primed with PL 718-2 primer.

Figure 16 presents data obtained from specimens prepared with M1113 adhesive with and without M6740 primer. As indicated in the discussion of table 3, one does not observe the significant increase in durability when this primer is used that was seen when the other three adhesive/primer systems were used.

Based upon the observations of this limited study, a program was conducted in which the effects of interchanging the primers and adhesives were studied. The four adhesives were used in conjunction with each of the three primers. In addition, two other primers, BR 127 and XA 3950, were used.

Based upon the fact that four adhesive systems, ADX 656.2, EA 9628, PL 717B, and M1113, were considered to be interchangeable for repairing bonded panels in Army helicopters, the durability data for the four systems were put together. Pooling the data allows one to evaluate the effects of the primers on the durability of the joints independently of the adhesive being used. Table 4 lists the times-to-failure at various stress levels for adhesive joints without any primer. Table 5 lists the pooled data for time-to-failure at various stress levels for the four adhesives with the five primers. Figure 17 graphically compares the durability of the joints containing the primers with those that did not contain primers. The XA 3950, BR 127, M6740 and the ADX 238.1 primers appear to be interchangeable with the

four adhesive systems. They have durability curves that are similar in slope. Their life expectancy appears to be longer than the joints which contain no primer. The PL 718.2 primer is also interchangeable with the various adhesives but appears to be more brittle since the durability curves show a slope which is more load-independent than the others.

A study of the data in table 5 and the type of failure indicate strongly that very stringent process controls will have to be established and adhered to at the user facility to control the application of the primer. In this evaluation, it was found that the majority of failures in bonded joints were between the adherend and the primer.

STUDY OF DEGRADATION IN ADHESIVE BONDED HONEYCOMB PANELS BY NONDESTRUCTIVE INSPECTION

An attempt was made to monitor degradation in an adhesive joint by nondestructive inspection (NDI). The NDI method used for this program was based upon a technique used by Kraska & Wolfe (refs. 11 and 12) in which they used the Harmonic Bond Tester with modified signal output to indicate a good bond, a panel with voids (delaminated areas), or a panel containing water. In this program the Harmonic Bond Tester is set up with an "active needle", that is, the instrument is set so that a good bond will register at 25 or mid-scale on the amplitude meter and the alarm invert switch is in the "ON" position. With these settings, a void in the bond line registers significantly up scale and water or corrosion in the bond line results in a significant down scale reading. The signal output was also fed to an oscilloscope and recorded on Polaroid film.

Figure 18 shows the oscilloscope traces obtained from a panel which was fabricated from two aluminum alloy skins bonded to honeycomb core with M1113. View A shows the trace obtained from the panel before it was exposed to accelerated aging by soaking in 60°C water. Views B and C show the traces obtained from the inspection of the panel after 14 days and 150 days conditioning, respectively. View D shows the trace obtained after 150 days exposure plus 32 days dry-out time. The amplitude readings were 25, 26, 22, and 25 respectively. These indicate a good bond in the panel. The traces show a small change at the second vertical grid line. Destructive testing of an unaged specimen and a specimen after the final 150 days plus 32 days dry-out revealed that the adhesive appears to be more brittle in the aged specimen than in the unaged specimen. The aged specimen failed from the skin; the unaged specimen failed cohesively.

Figure 19 shows the oscilloscope traces obtained from a panel which was fabricated from two aluminum skins bonded to aluminum honeycomb core with PL 717B. View A shows the trace obtained with an unaged panel. Views B, C and D show the traces after 7, 14 and 150 days accelerated aging by immersion in 60°C water. View E shows the trace after 150 days accelerated aging and 32 days dry-out time. The amplitude readings corresponding to the five traces were 25, 35, 35, 29, and 30 respectively. These would indicate generally good bonds. The oscilloscope traces show the following: after the first seven days the adhesive is absorbing moisture and the modulus of the adhesive is changing in the joint. This absorption continued through the 14th day and then the signal started to diminish slowly which indicates that the moisture may have been collecting at the interface or in the cells. The signal obtained after the 32 day dry-out time appears normal, but is slightly larger than the original, indicating possible retention of moisture. When the specimen was destructively tested, the bond was determined to have been intact but the failure mode had changed from cohesive (for the unaged specimen) to adhesive. There was evidence of corrosion on the core cell walls, indicating that water had been present. There also was some indication of corrosion on parts of the skin.

Figure 20 shows the oscilloscope traces obtained from a panel fabricated with EA 9628 adhesive. View A shows the trace obtained for the unaged panel, while View B is a typical trace obtained for the panel throughout the accelerated aging period. View C shows the trace after 17 days dry-out time. View D was obtained from the outside ¼ inch of the panel. These oscilloscope traces indicate the following: the adhesive absorbed moisture in the early stages (first 2 days) and remained constant throughout the 150-day accelerated aging period. After drying for 17 days, the shape of the trace is again similar to the unaged specimen, but somewhat larger, indicating that some moisture may be retained. View D indicates either water or corrosion in the joint along the outer edge. The amplitude readings for the four views were 29, 33, 28 and 4 respectively, indicating a good bond integrity in the panel except along the outer edge where either corrosion or water was present.

Destructive testing of the aged and dried panel indicated that the mode of failure was predominantly cohesive throughout the panel. The outer row of core cells showed corrosion where the water had entered this row of cells through holes caused by cutting the specimen along the cell boundary. The center cells were clean and bright.

Figure 21 shows the oscilloscope traces obtained from a panel fabricated with ADX 656.2 adhesive. View A shows the trace obtained from the unaged panel. View B shows the trace obtained after 1 day of accelerated aging in 60 °C water; this remained typical throughout the aging time. Views C and D show the trace obtained after 150 days aging plus 3 and 32 days of dry-out time, respectively. The oscilloscope traces indicate that the adhesive absorbed moisture very rapidly (first day) and retained it throughout the 150-day immersion. The panel dries out rather slowly as indicated by the slowly diminishing trace (views C & D). The amplitude readings indicated a good structure: 30, 34, 25 and 25 for the four views, respectively.

Destructive testing revealed a slight gray coating on many cell walls, indicating that moisture had entered the panel. The bond integrity was good, requiring a significant force to peel back the skin. The type of failure was mixed; the adhesive fillet around the core cell generally failed cohesively, while the adhesive over the cell was approximately 50% failed from the skin and 50% from the cell. In the control (unaged) panel the adhesive failed mainly cohesively in the fillet, leaving adhesive on the skin. The aged panel also showed water entry into the open outer row of cells, and this was detectable by NDI. A number of other adhesives were also used to prepare test panels to evaluate the NDI technique for monitoring degradation. These systems were not among the ones accepted for the repair of honeycomb panels and will not be identified by trade name or number, but are used here to demonstrate the ability of this technique to determine defects in the structure. They are all 121°C-curing adhesives.

Figure 22 shows the oscilloscope trace obtained with one of these systems. This figure shows the trace of the unaged specimen in view A. View B shows the trace of the specimen after it had absorbed moisture for 67 days. In view C, after 150 days immersion, the trace shows a void along the top edge, approximately 1.27 cm (1/2 inch) from the edge, and view D shows the trace obtained in a narrow (approximately 0.32 cm (1/8 inch) wide) area just below the void. This narrow trace indicates either water or corrosion in the joint. View E is the trace obtained in this 0.32 cm band after drying 32 days. This trace indicates the bond was intact but degraded. The trace observed in view D is probably from an accumulation of moisture in the joint. The amplitude readings for the five views were 25, 28, 50 plus, 1, and 11, respectively. These indicate a good bond for the first two traces, a delamination for the third, water or corrosion for the fourth, and a degraded bond for the fifth. Destructive testing of this panel required relatively little force to peel the skin from the panel. The

failure was mainly adhesive from the skin. When the skin on the original panel was peeled before aging, the failure was cohesive.

Figure 23 shows the traces obtained when still another adhesive system was used to fabricate honeycomb panels. View A is the unaged panel. After one day of accelerated aging in the 60°C water (view B), the trace swelled, indicating the absorption of water. This signal diminished as shown in view C, indicating that degradation was taking place. View D was obtained after 150 days aging plus 32 days dry-out time. The amplitude readings were 23, 26, 28 and 25, respectively, indicating a good bond. Destructive testing of the aged panel showed relatively little force was required to peel back the skin. The failure mode was adhesive to the skin, with a glossy finish under the test area, indicating that the panel probably was close to delamination.

The observations made during this limited investigation of the use of nondestructive inspection to monitor degradation in bonded honeycomb structures show that there is real promise for this technique. Further work is required to establish a broader base for the interpretation of the combination of oscilloscope signals and the amplitude readings. It is, however, interesting to note that the NDI technique showed that the four adhesive systems selected from the first phases of the investigation of new adhesives for the repair of honeycomb panels at depot maintenance level showed the least degradation.

CONCLUSIONS

1. Four adhesive systems have been determined to give improvements over the systems presently used to fabricate and repair bonded honeycomb panels in Army helicopters at depot level. These systems will not change the stiffness of the panel but will increase the fatigue life and static durability of the structure. The four systems showed good retention of properties after -20°C storage for extended times and were not detrimentally affected by shop storage at 23°C and 50% RH for up to 35 days.

2. Careful analysis of a fractured joint may indicate the origin of failure, the mechanism by which the failure propagated and an estimate of the load the joint experienced at the time of failure.

3. The use of corrosion-inhibiting primers can increase the life expectancy of a bonded joint if very stringent process controls are established and used at the fabrication or repair facility.

4. A technique has been developed which follows degradation in an adhesive-bonded honeycomb panel. A Harmonic Bond Tester, used in conjunction with an oscilloscope and a recording camera, can detect changes in the adhesive caused by moisture, voids, onset of corrosion in the joint, or water in the interface. This NDI technique showed that the four adhesive systems accepted in the first part of this overall program showed less degradation than all other systems investigated.

REFERENCES

1. R. F. Wegman, M. C. Ross, E. A. Garnis, and S. A. Slota, "New Bonding Systems for Depot Maintenance of Aircraft Honeycomb Structures, Part 1 Preliminary Evaluation of Ten Structural Adhesives," PATR 4810, Nov 1975

2. R. F. Wegman, M. C. Ross, S. A. Slota, K. E. Gerlach, "New Bonding Systems for Depot Maintenance of Aircraft Honeycomb Structures, Part II Evaluation of Fatigue Properties of Four Structural Adhesives, " PATR 4910, May 1976

3. R. F. Wegman, M. C. Ross, and E. A. Garnis, "New Bonding Systems for Depot Maintenance of Aircraft Honeycomb Structures, Part III Evaluation of Processing Variables on the Durability of Bonded Joints," (In Press)

4. W. J. Russell, "New Bonding Systems for Depot Maintenance of Aircraft Honeycomb Structures, Part IV Fracture Analysis of Adhesive Bonded Joints Failed in Fatigue," Technical Report ARLCD-TR-77087 (in press)

5. R. F. Wegman, W. C. Hamilton, and M. J. Bodnar, "A Study of Environmental Degradation of Adhesive Bonded Titanium Structures in Army Helicopters," 4th National SAMPE Technical Conference, Oct 1972

6. R. F. Wegman and M. J. Bodnar, "Durability of Bonded Titanium Joints Increased by New Process Treatments," 18th National SAMPE Symposium, Vol 16, Apr 1973

7. R. F. Wegman and M. J. Bodnar, "Structural Adhesive Bonding of Titanium-Superior Surface Treatment Preparation Technique," SAMPE Quarterly, Vol 5, No. 1, Jan-Feb 1974

8. R. F. Wegman and M. J. Bodnar, "Preproduction Evaluation of an Improved Titanium Surface Prebonding Process," 20th National SAMPE Symposium, Vol 20, May 1975

9. R. F. Wegman, "Field Maintenance Level Repair Methods for Aircraft Honeycomb Panel," Technical Report 4914, Picatinny Arsenal, Dover, NJ, Feb 1976

10. Annual Book of ASTM Standards, Part 16, "Structural Sandwich Construction; Wood; Adhesives," 1973, Method No. D 2919-71

11. I. R. Kraska, and J. J. Wolf, "Nondestructive Inspection of Shelter Panels," General American Transportation Corp, Air Force Civil Engineering Center, Technical Report 74-3, May 1974

12. I. R. Kraska, and J. J. Wolf, "Nondestruction Inspection of Shelter Panels," General American Transportation Corp, Final Report Air Force Civil Engineering Center, Technical Report 75-2, Jan 1975

13. R. F. Wegman, M. C. Ross, E. A. Garnis, S. A. Slota, "A Technique for Assessing the Durability of Structural Adhesives," ARLCD-TR-77010, May 1978

Table 1. Physical properties of honeycomb panels

Adhesive	Climbing drum peel		Failure	Honeycomb panel stiffness			
				Core shear stress		Facing stress	
	Kg/7.62 cm	lb/3 in. width		MPa	Psi	MPa	Psi
Control A	40.4	89	Adhesive	2.41	350	0.37	53
M 1113	59.0	130	Cohesive	2.41	350	0.37	53
EA 9628	60.0	132	Cohesive	2.68	380	0.39	57
ADX 656.2	74.8	165	Cohesive	2.65	385	0.40	58
PL 717B	89.4	197	Cohesive	2.90	420	0.44	64

Table 2. Summary of hot-water soak residual strength vs control strengths

	Shear strength									
	Control					60°C Water soak				
	23°C		60°C		Thermal	100 hrs		1,000 hr		Total
Adhesive	MPa	Psi	MPa	Psi	Loss, %	MPa	Psi	MPa	Psi	Loss, %
M 1113	37.3	5410	29.4	4260	21	22.7	3290	20.0	2900	46
EA 9628	32.9	4770	30.1	4370	8	30.5	4420	24.3	3530	26
ADX 656.2	39.9	5790	33.9	4910	15	29.6	4290	21.9	3170	45
PL 717B	38.9	5640	29.9	4330	23	30.2	4380	25.2	3660	35

Table 3. 60°C/95% RH stressed durability data for adhesives with or without primer

Adhesive	Primer	Time to failure (hrs) at stress of: 17.9MPa (2600 psi)	16.5MPa (2400 psi)	15.2MPa (2200 psi)	13.8MPa (2000 psi)	12.4MPa (1800 psi)	11.0MPa (1600 psi)	8.3MPa (1200 psi)	5.5MPa (800 psi)	2.8MPa (400 psi)
ADX656.2	None	-	-	-	174	-	335	545	942	1380
					196		368	579	947	1380
					208		388	645	954	1380
					250		421	698	1083	1380
					207		378	617	982	1380
	ADX238.1	60	141	-	438	-	-	-	-	-
		66	166		678					
		140	169		699					
		167	178		738					
		108	164		638					
EA9628	None	-	-	-	131	-	318	613	1400	a
					144		332	638	1452	a
					159		377	735	1552	a
					159		414	782	1519	a
					148		360	692	1456	
	ADX238.1	27	148	400	569	-	-	-	-	-
		80	250	406	1080					
		92	280	654	1368					
		95	285		1536					
		74	240	487	1140					

[a] Tested after 1519 hours; shear strength 34.9 MPa (5060 psi) (avg).

Table 3. (Cont'd)

Adhesive	Primer	17.9MPa (2600 psi)	16.5MPa (2400 psi)	15.2MPa (2200 psi)	13.8MPa (2000 psi)	12.4MPa (1800 psi)	11.0MPa (1600 psi)	8.3MPa (1200 psi)	5.5MPa (800 psi)	2.8MPa (400 psi)
		Time to failure (hrs) at stress of								
PL-717B	None	-	-	-	44 55 57 80 59 (avg)	-	151 176 197 197 180 (avg)	311 363 389 409 368 (avg)	1100 1350 1350 c >1267 (avg)	b b b b
	PL718-2	10 12 15 31 17 (avg)	21 35 54 66 44 (avg)	148 182 182 - 171 (avg)	331 336 382 443 360 (avg)	-	-	-	-	
M-1113	None	-	-	-	94 101 140 155 122 (avg)	-	217 218 235 238 227 (avg)	263 329 354 396 336 (avg)	503 623 671 672 617 (avg)	1248 1446 1470 1490 1414 (avg)
	M6740	43 46 53 59 50 (avg)	49 53 54 66 55 (avg)	84 96 - - 90 (avg)	96 159 - - 128 (avg)	172 227 - - 200 (avg)	-	-	-	-

[b] Tested after 1530 hours; shear strength 29.6 MPa (4290 psi) (avg).

[c] Tested after 1530 hours; shear strength 25.5 MPa (3700 psi) (avg).

Table 4. Pooled durability data for the four adhesive systems with no primer

Time to failure at stress of			
13.8MPa (2000 psi)	11.0MPa (1600 psi)	8.3MPa (1200 psi)	5.5MPa (800 psi)
174[a]	335[a]	545[a]	942[a]
196[a]	368[a]	579[a]	947[a]
208[a]	388[a]	645[a]	954[a]
250[a]	421[a]	698[a]	1083[a]
131[b]	318[b]	613[b]	1400[b]
144[b]	332[b]	638[b]	1452[b]
159[b]	377[b]	735[b]	1452[b]
159[b]	414[b]	782[b]	1519[b]
94[c]	217[c]	263[c]	503[c]
101[c]	218[c]	329[c]	623[c]
140[c]	235[c]	354[c]	671[c]
155[c]	238[c]	396[c]	672[c]
44[d]	151[d]	311[d]	1100[d]
55[d]	176[d]	363[d]	1350[d]
57[d]	197[d]	389[d]	1350[d]
80[d]	197[d]	409[d]	
134	286	503	1006

[a]Adhesive ADX656.2

[b]Adhesive EA9628

[c]Adhesive M-1113

[d]Adhesive PL-717B

Table 5. Pooled durability data for the four adhesive systems with various primers

Primer	Time to failure at stress of 17.9MPa (2600 psi)	15.2MPa (2200 psi)	12.4MPa (1800 psi)
M-6740	158[c]	178[c]	726[c]
	143[c]	167[c]	714[c]
	162[c]	159[c]	701[c]
	102[c]	224[c]	649[c]
	53[d]	137[d]	263[d]
	35[d]	48[d]	137[d]
	98[a]	116[d]	239[d]
	35[d]	114[d]	234[d]
	130+[b]	395[a]	375[a]
	130+[b]	480[a]	427[a]
	130+[b]	444[a]	451[a]
	130+[b]	398[a]	460[a]
	76[a]	143[d]	778[d]
	98[a]	41[d]	630[d]
	107[a]	30[d]	419[d]
	120[a]	13[d]	592[d]
	107+	192	487
PL718.2	3[c]	53[c]	182[c]
	28[c]	1[c]	269[c]
	2[c]	1[c]	223[c]
	1[c]	8[c]	276[c]
	32[c]	43[c]	252[d]
	10[c]	78[c]	232[d]
	21[d]	59[d]	211[d]
	19[d]	79[d]	162[d]
	36[d]	117[d]	152[a]
	12[d]	85[d]	86[a]
	22[a]	33[a]	24[a]
	40[a]	28[a]	104[a]
	18[a]	30[a]	173[b]
	22[a]	90[a]	205[b]
	1[b]	1[b]	270[b]
	1[b]	2[b]	177[b]
	2[b]	3[b]	
	1[b]	2[b]	
	1[b]		
	1[b]		
	11[b]		
	1[b]		
	13	40	187

[a] Adhesive ADX656.2
[b] Adhesive EA9628
[c] Adhesive M-1113
[d] Adhesive PL-717B

Table 5. (Cont'd)

Primer	17.9MPa (2600 psi)	15.2MPa (2200 psi)	12.4MPa (1800 psi)
ADX238.1	63[c]	77[c]	381[c]
	66[c]	78[c]	410[c]
	40[c]	115[c]	372[c]
	2[c]	91[c]	422[c]
	74[d]	118[b]	145[d]
	50[d]	67[b]	198[d]
	53[d]	59[b]	118[d]
	26[d]	56[b]	192[a]
	130+[b]	269[a]	23[a]
	130+[b]	230[a]	141[a]
	130+[b]	255[a]	291[a]
	130+[b]	285[a]	383[b]
	148[a]	2[d]	357[b]
	226[a]	12[d]	368[b]
	118[a]	5[d]	385[b]
	240[a]	7[d]	
	102+	108	279
XA3950	189[c]	307[c]	915+[c]
	194[c]	271[c]	915+[c]
	167[c]	290[c]	915+[c]
	220[c]	269[c]	915+[c]
	7[d]	150[d]	210[d]
	35[d]	135[d]	262[d]
	31[d]	172[d]	300[a]
	3[d]	209[d]	597[a]
	130+[b]	722[a]	8[a]
	130+[b]	744[a]	329[a]
	130+[b]	973[a]	798[b]
	130+[b]	410[a]	903[b]
	29[a]	36[b]	923[b]
	29[a]	13[b]	893[b]
	54[a]	17[b]	
	50[a]	69[b]	
	96+	299	635+

[a]Adhesive ADX656.2

[b]Adhesive EA9628

[c]Adhesive M-1113

[d]Adhesive PL-717B

Table 5. (Cont'd)

Primer	17.9MPa (2600 psi)	15.2MPa (2200 psi)	12.4MPa (1800 psi)
BR127	58[c]	77[c]	665[c]
	186[c]	210[c]	691[c]
	61[c]	70[c]	534[a]
	24[c]	255[c]	390[a]
	95[d]	183[d]	330[a]
	170[d]	191[d]	386[a]
	53[d]	178[d]	506[b]
	51[d]	320[d]	445[b]
	130+[b]	273[a]	542[b]
	130+[b]	412[a]	539[b]
	130+[b]	402[a]	
	130+[b]	447[a]	
	160[a]	2[b]	
	130[a]	1[b]	
	86[a]	56[b]	
	172[a]		
	110+	192	503

[a]Adhesive ADX656.2

[b]Adhesive EA9628

[c]Adhesive M1113

[d]Adhesive PL717B

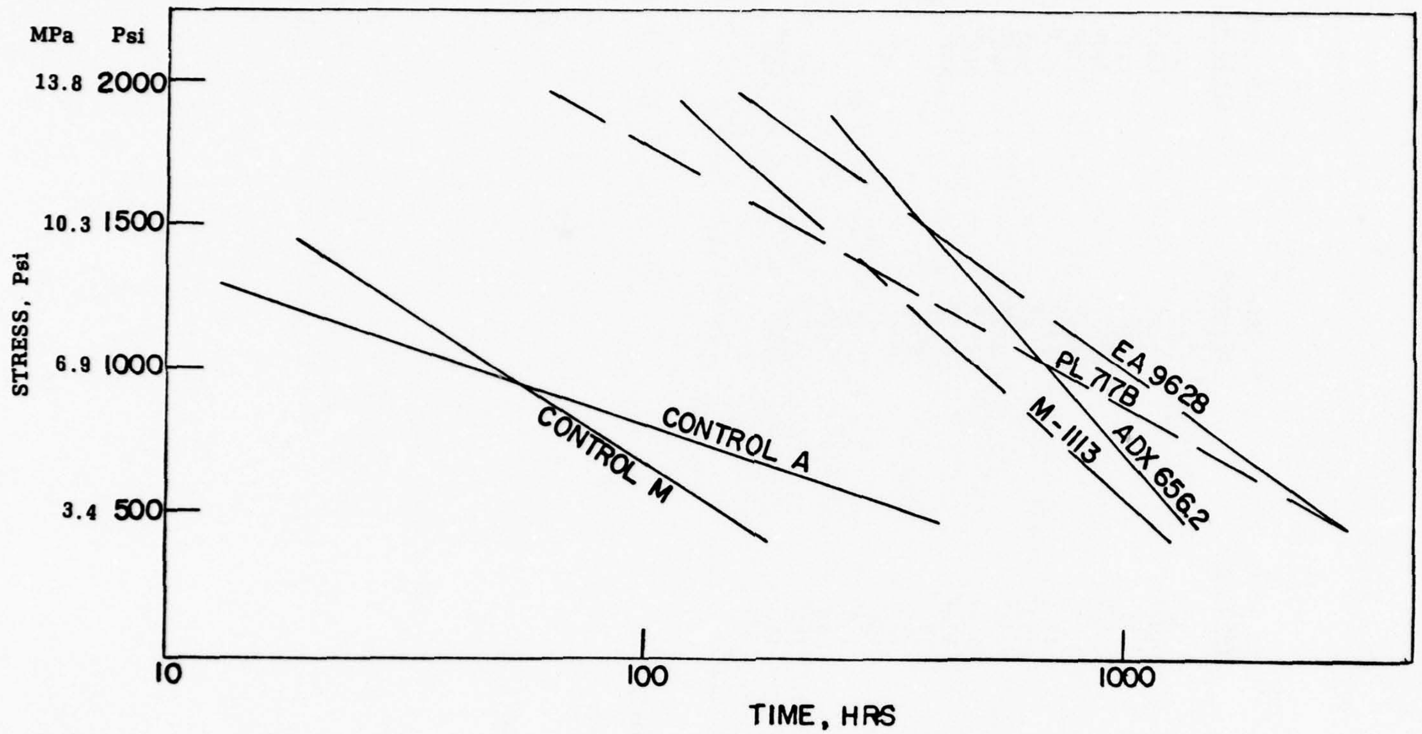


Figure 1. Comparison of stressed durability curves for the adhesives in FPL-etched aluminum joints.

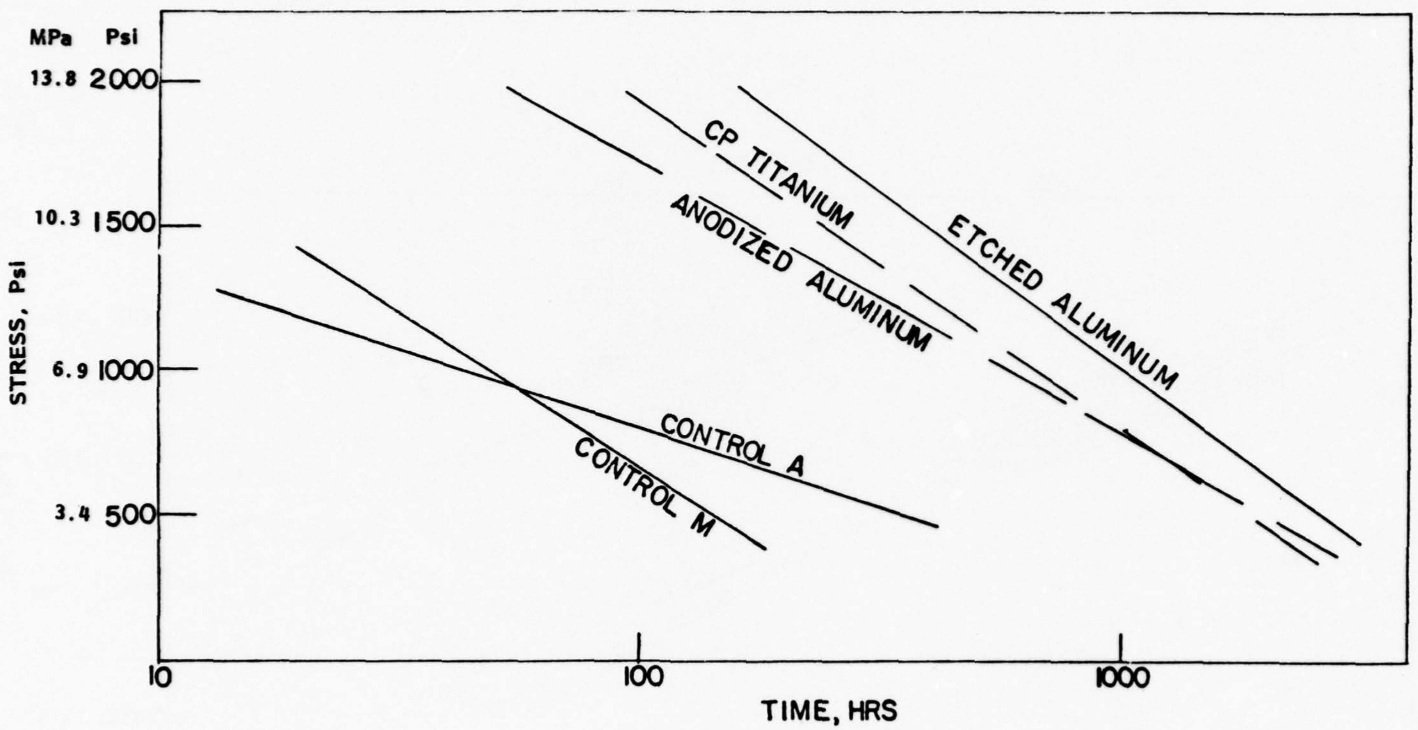


Figure 2. Durability curves for EA 9628 adhesive.

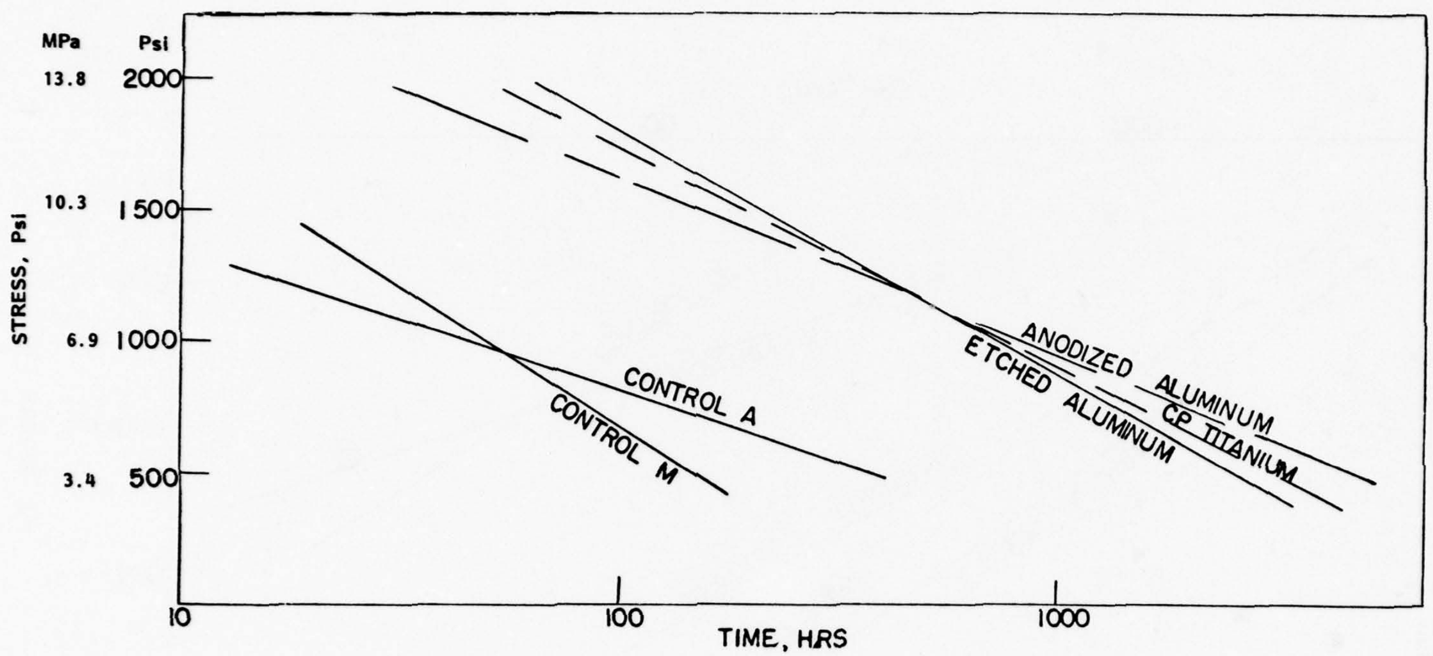


Figure 3. Durability curves for PL 717B adhesive.

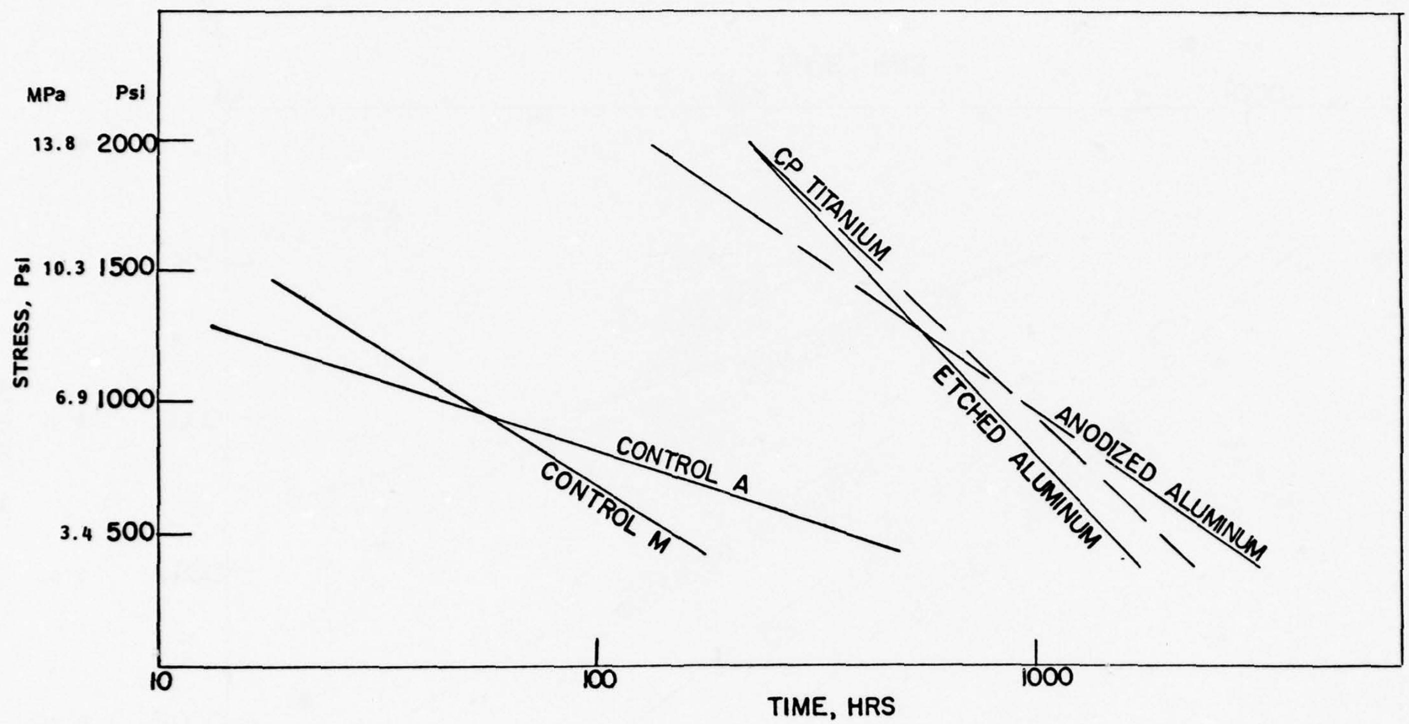


Figure 4. Durability curves for ADX 656.2 adhesive.

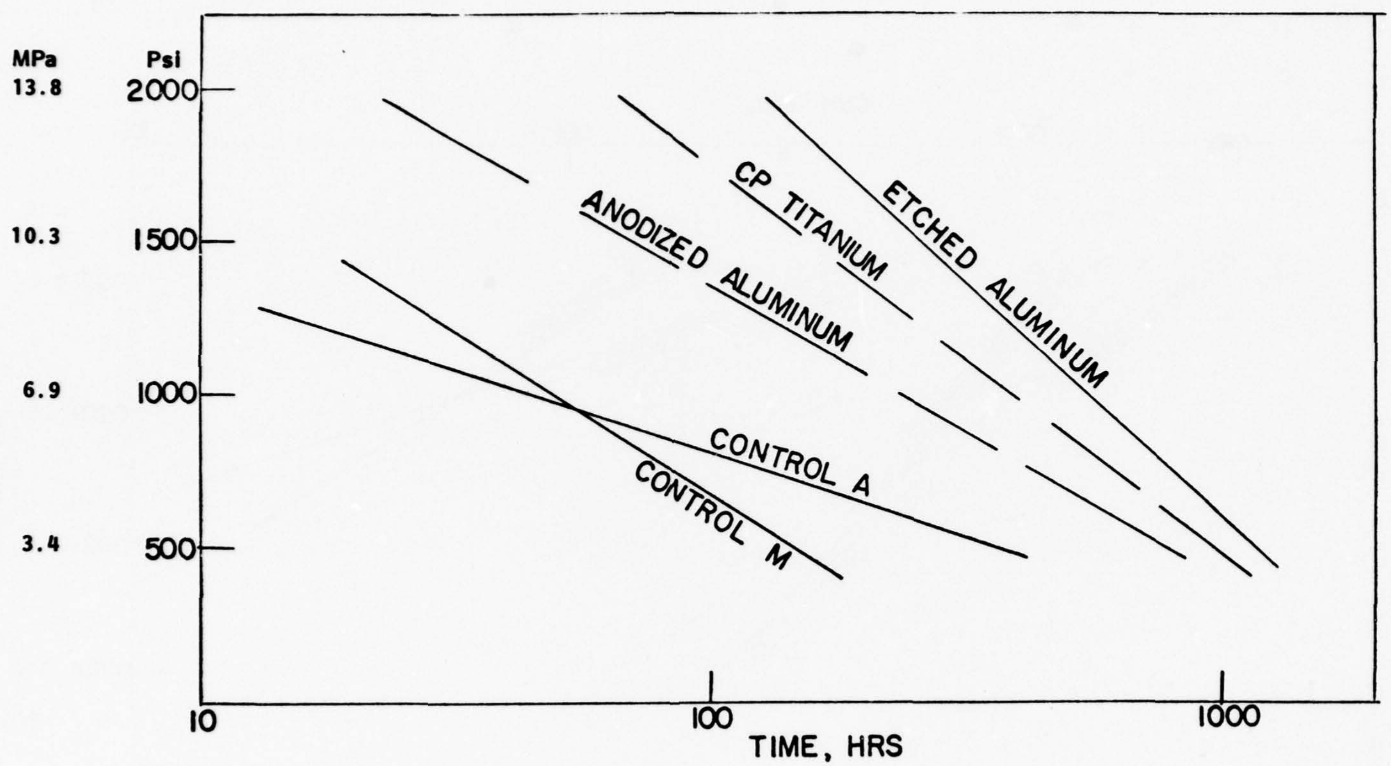


Figure 5. Durability curves for M 1113 adhesive.

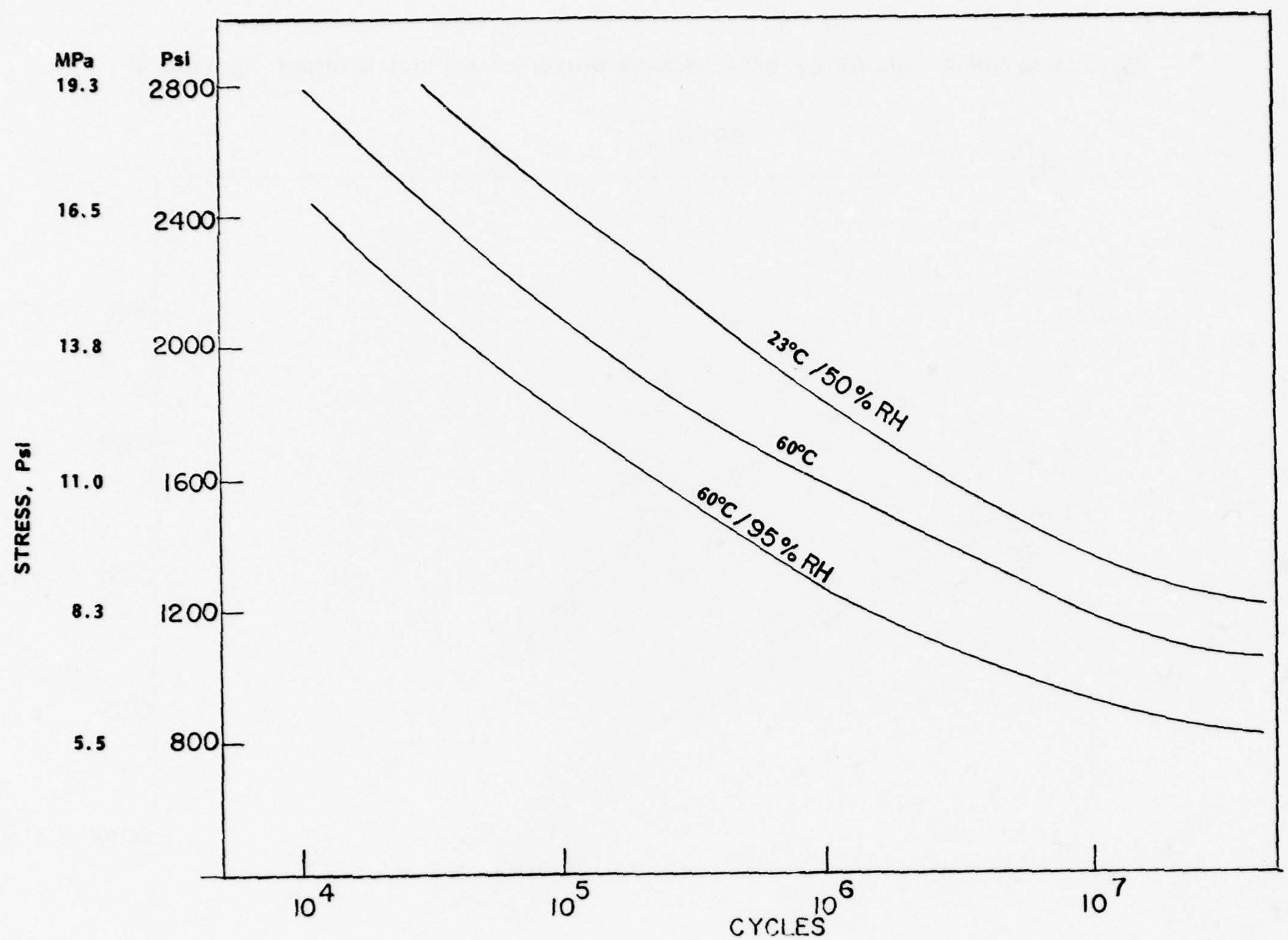


Figure 6. Typical fatigue curves at various test conditions.

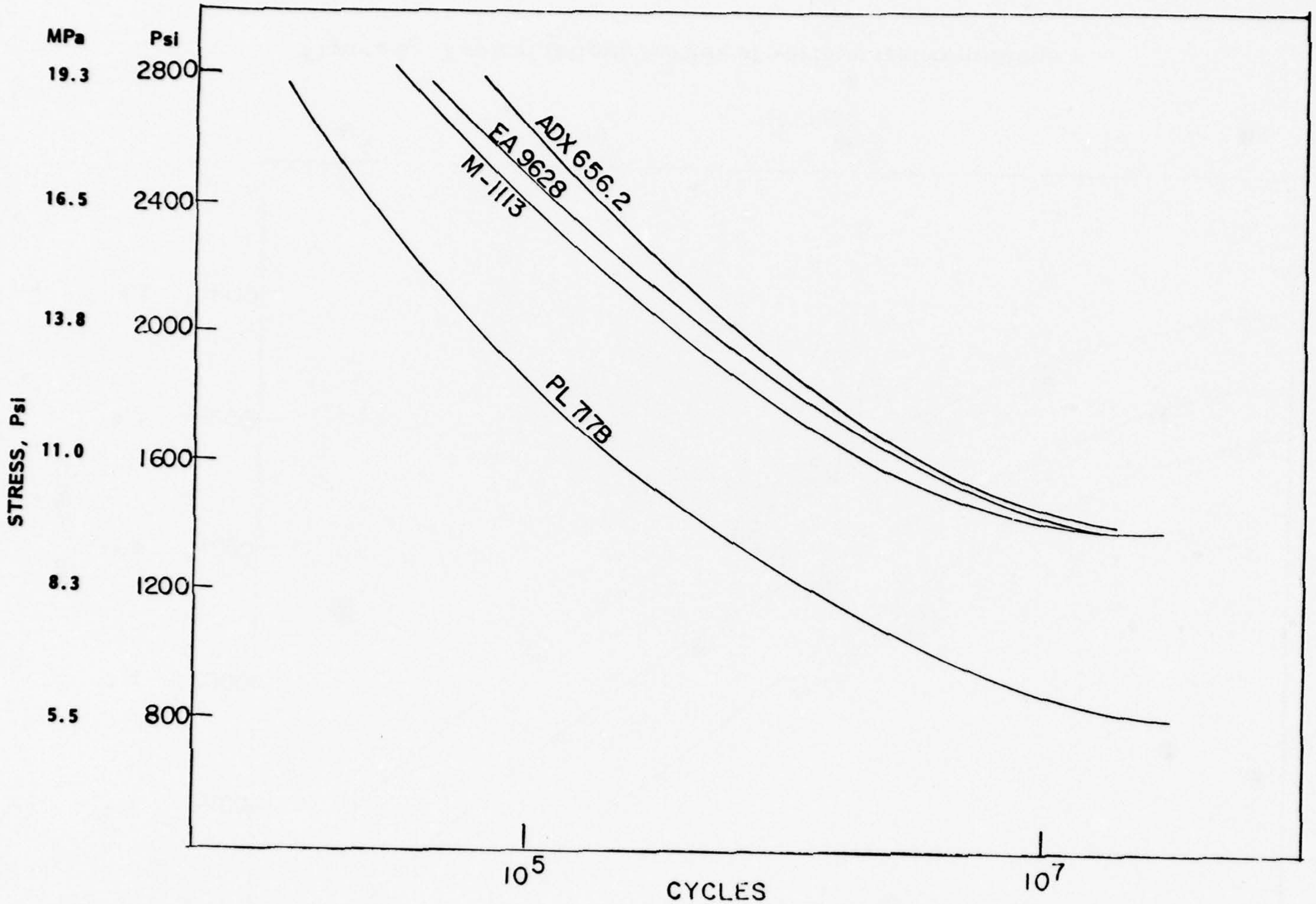


Figure 7. Fatigue data for adhesive-bonded 2024-T3 aluminum joints at 23°C.

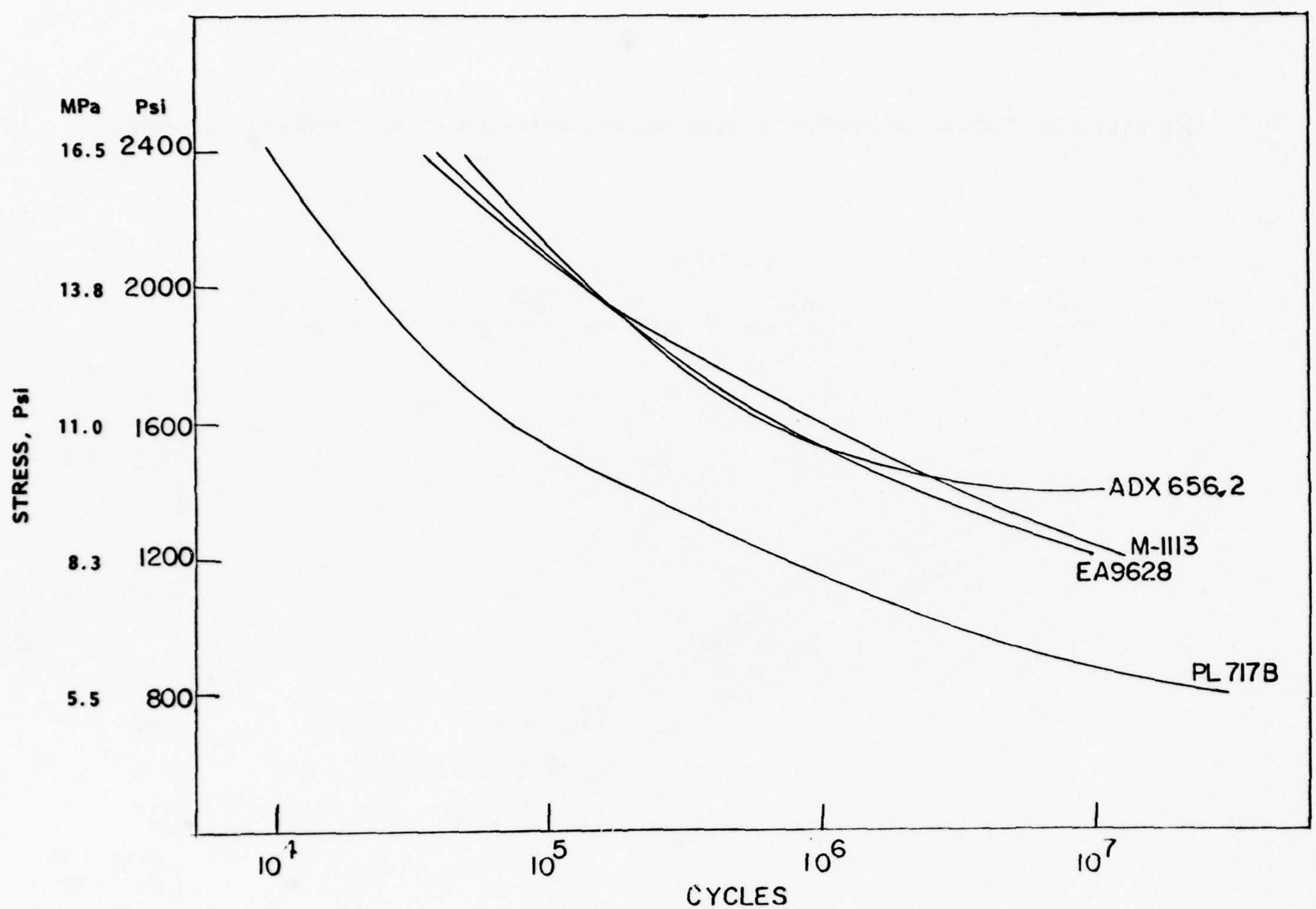


Figure 8. Fatigue data for adhesive-bonded 2024-T3 aluminum joints at 60°C.

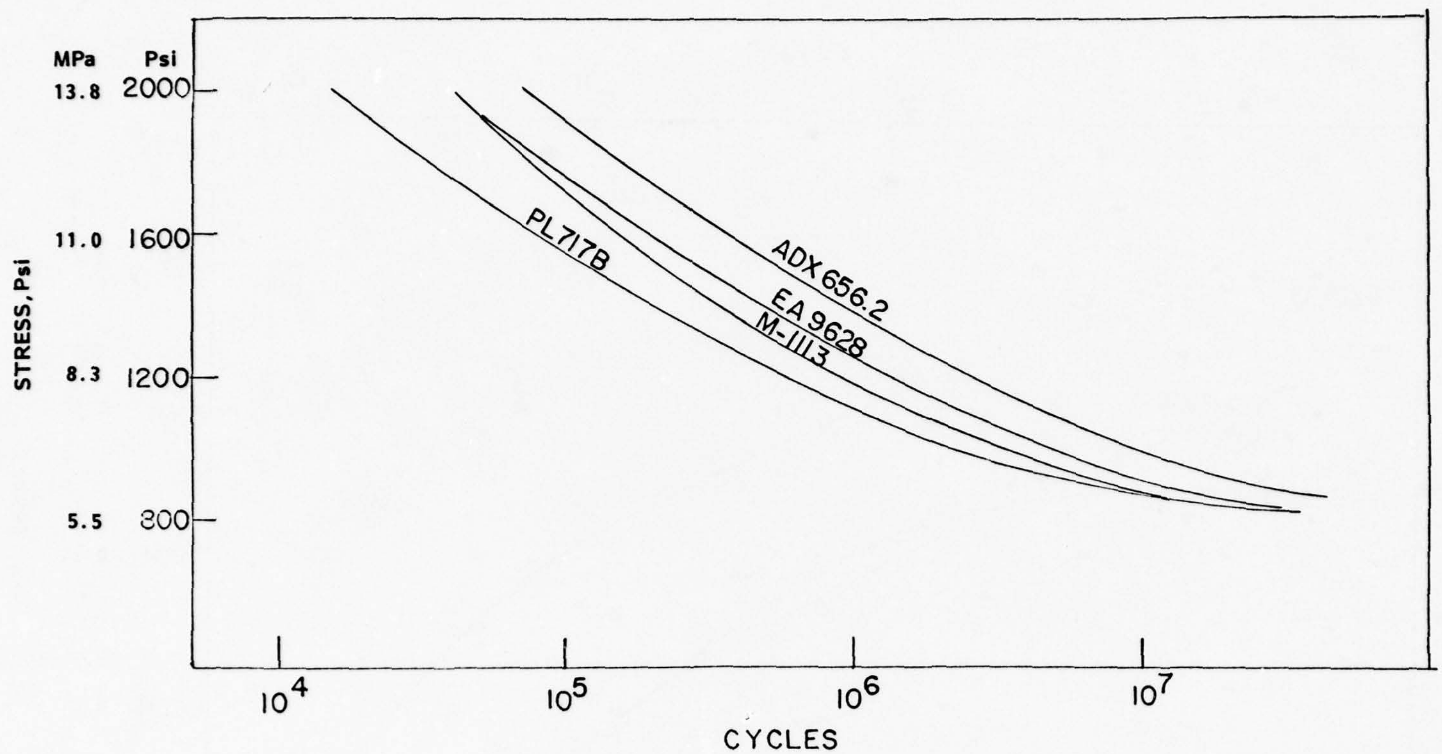


Figure 9. Fatigue data for adhesive-bonded 2024-T3 aluminum joints at 60°C/95% RH.

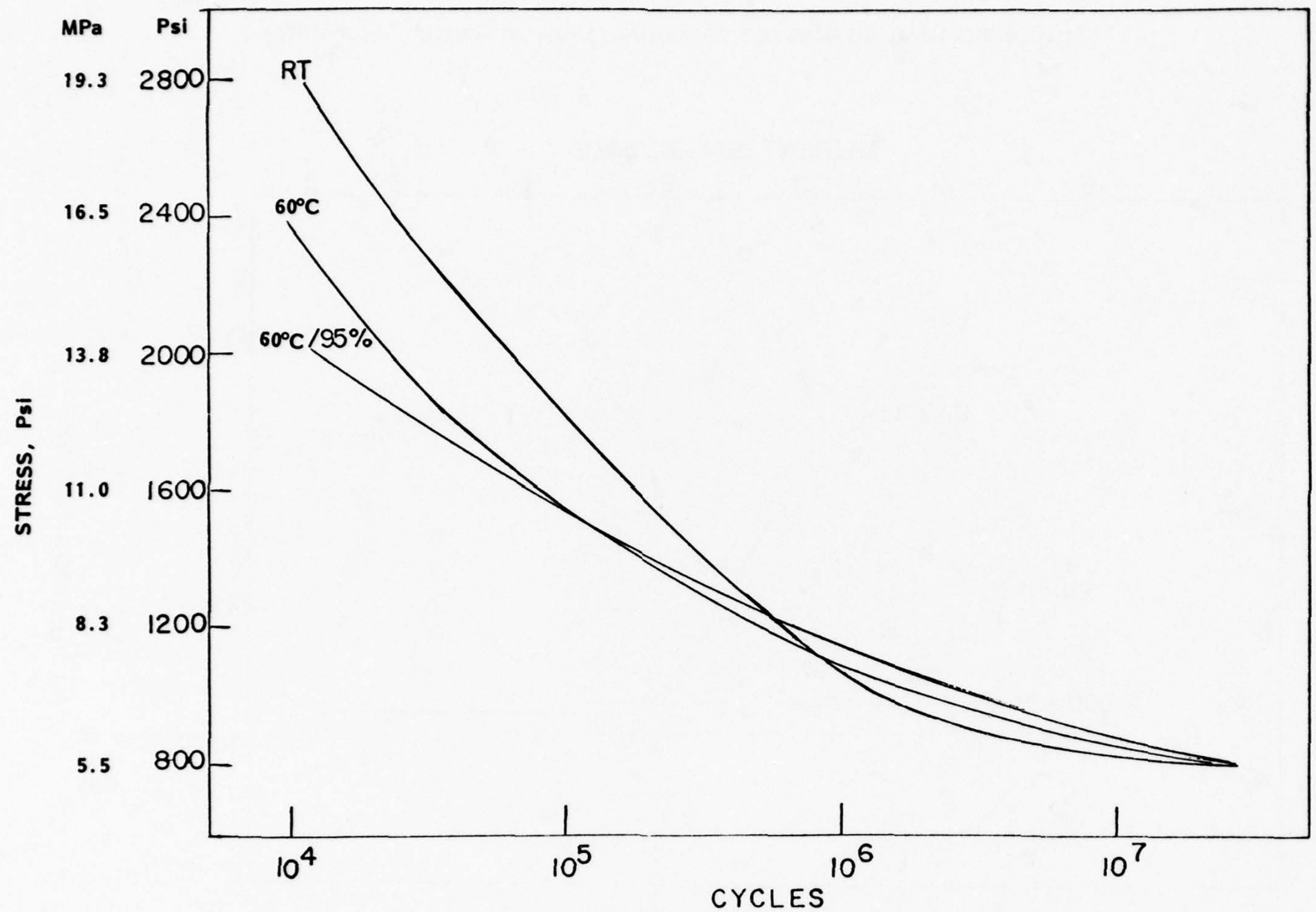


Figure 10. Fatigue data for PL 717B-bonded 2024-T3 aluminum joints.

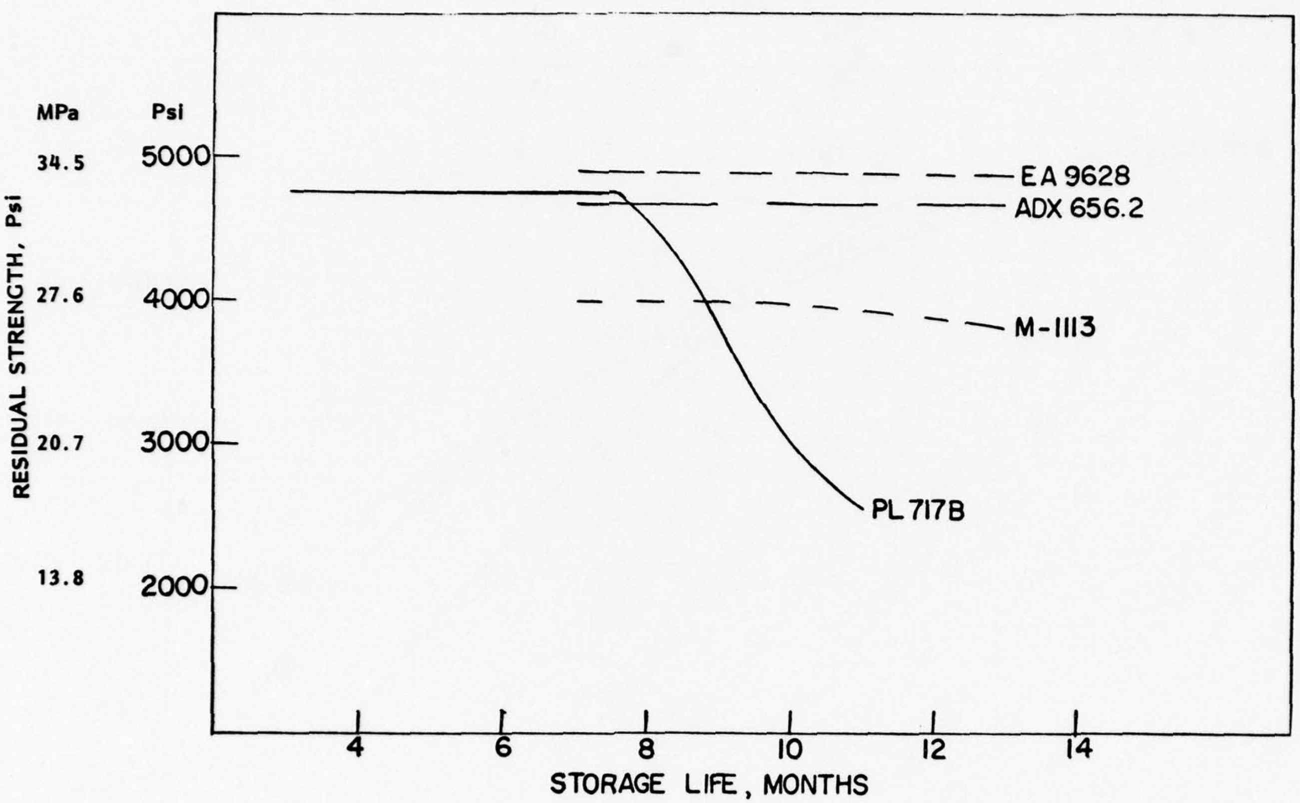


Figure 11. Effect of -20°C adhesive storage on joint durability.

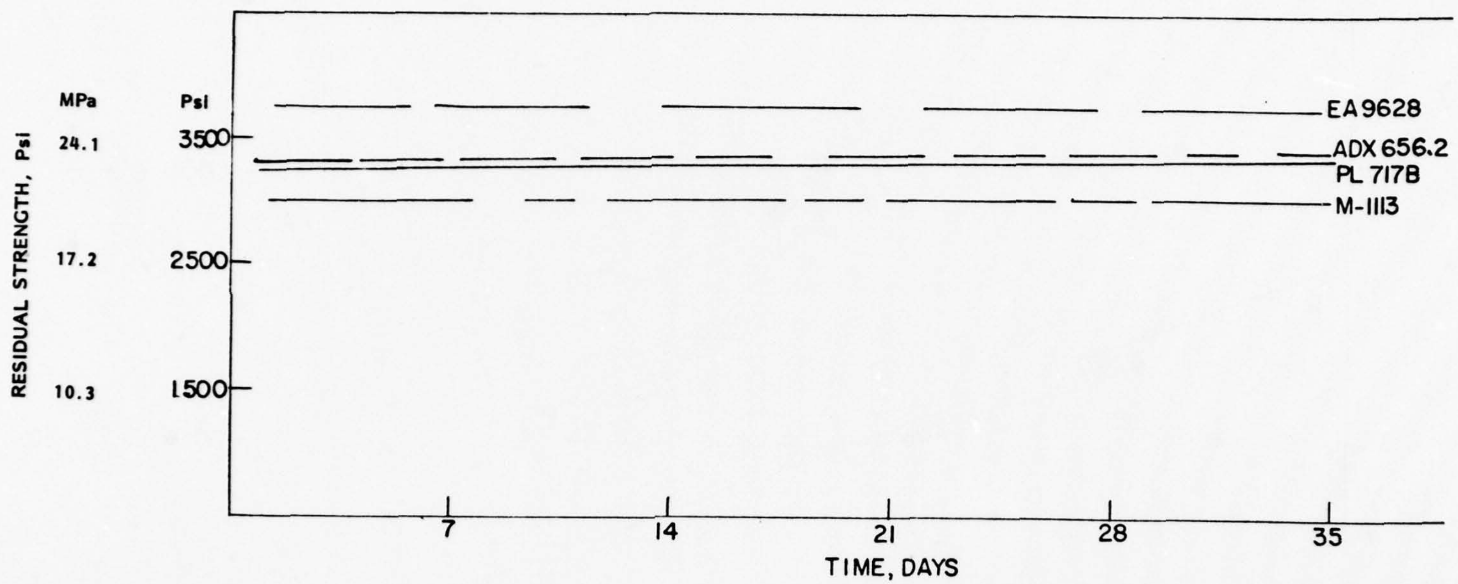


Figure 12. Effect of 23°C/50% RH out-time on joint durability.

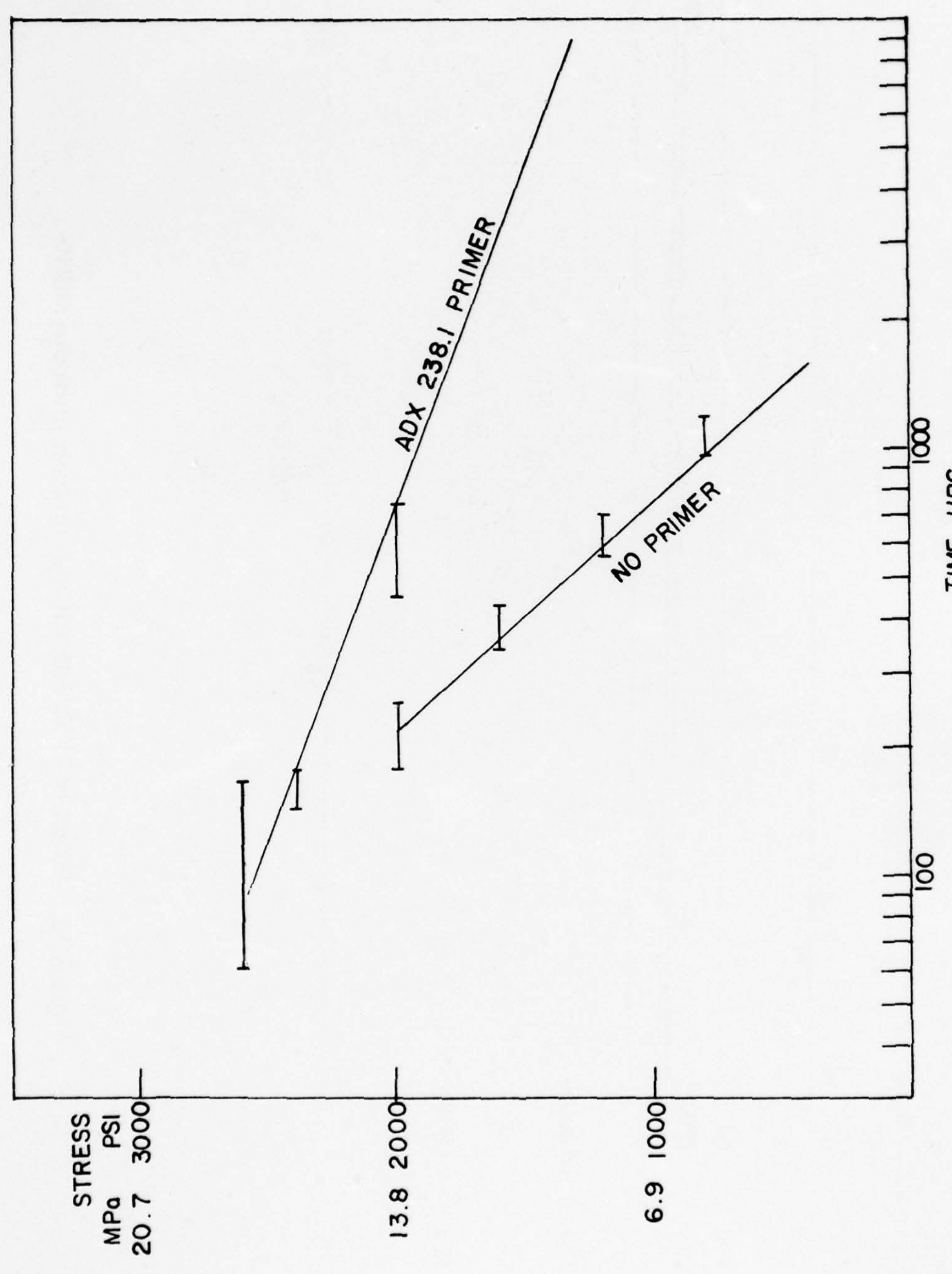


Figure 13. Durability curves for ADX 656.2 with and without ADX 238.1 primer.

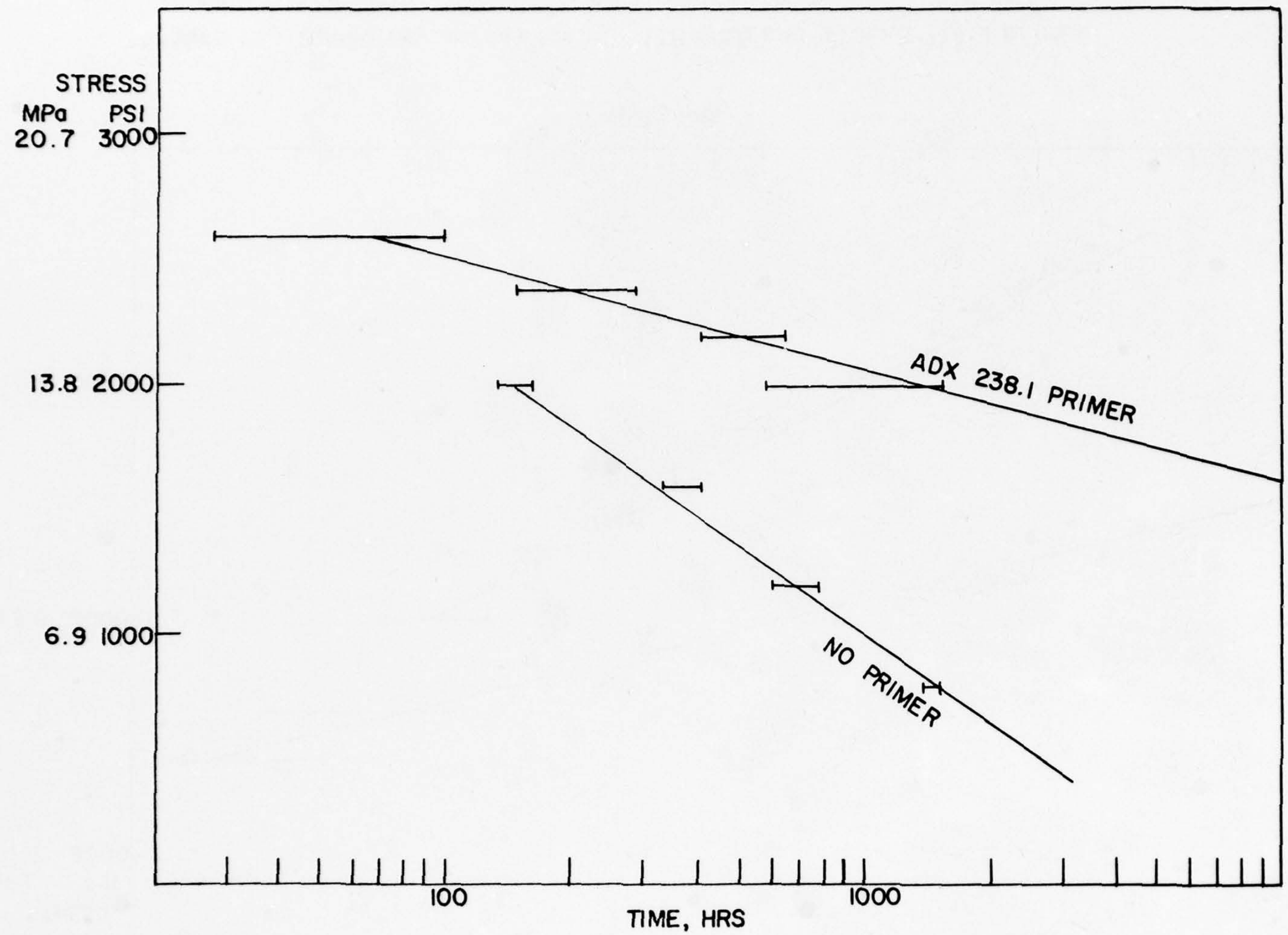


Figure 14. Durability curves for EA 9628 with and without ADX 238.1 primer.

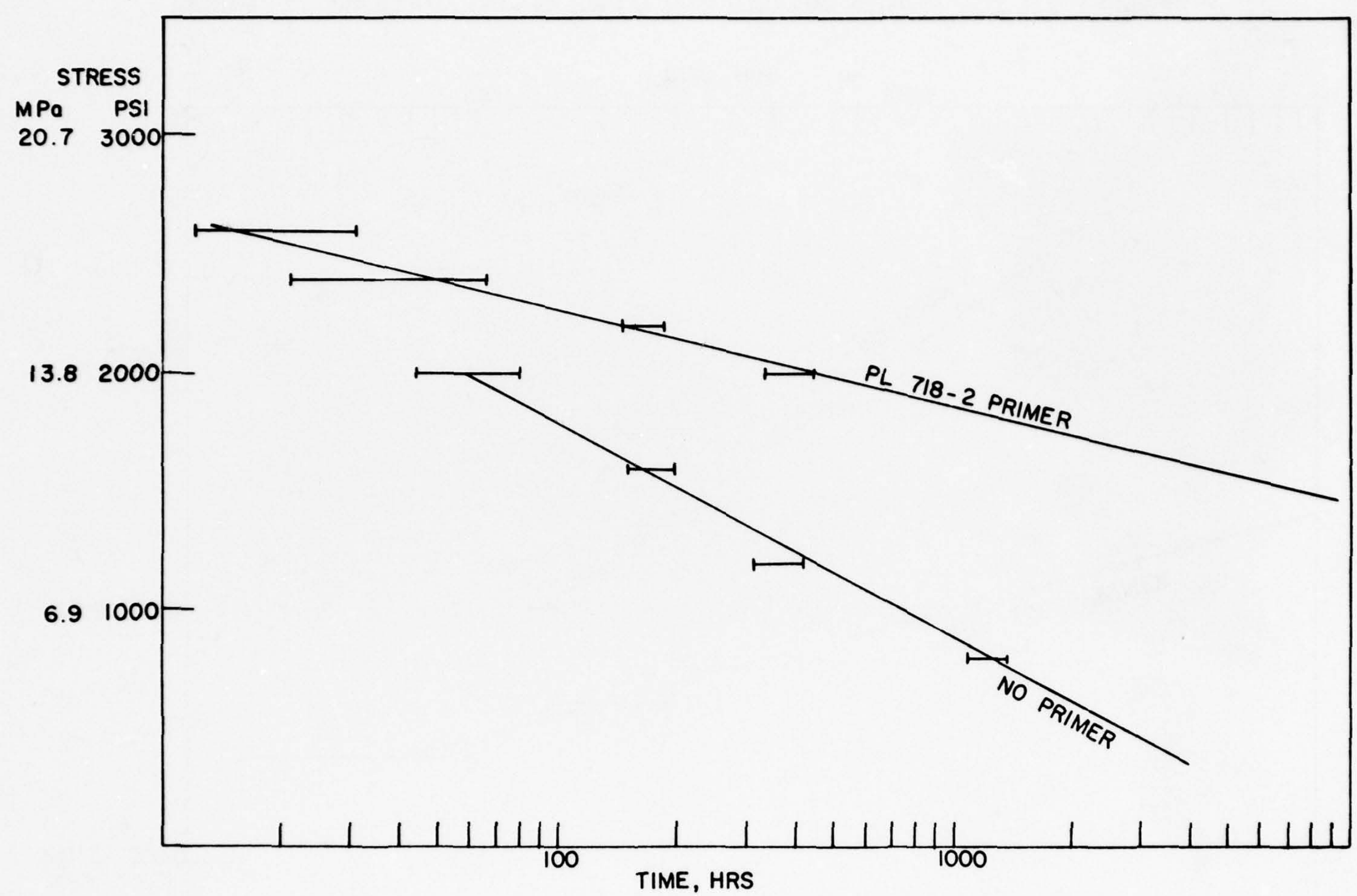


Figure 15. Durability curves for PL 717B with and without 718.2 primer.

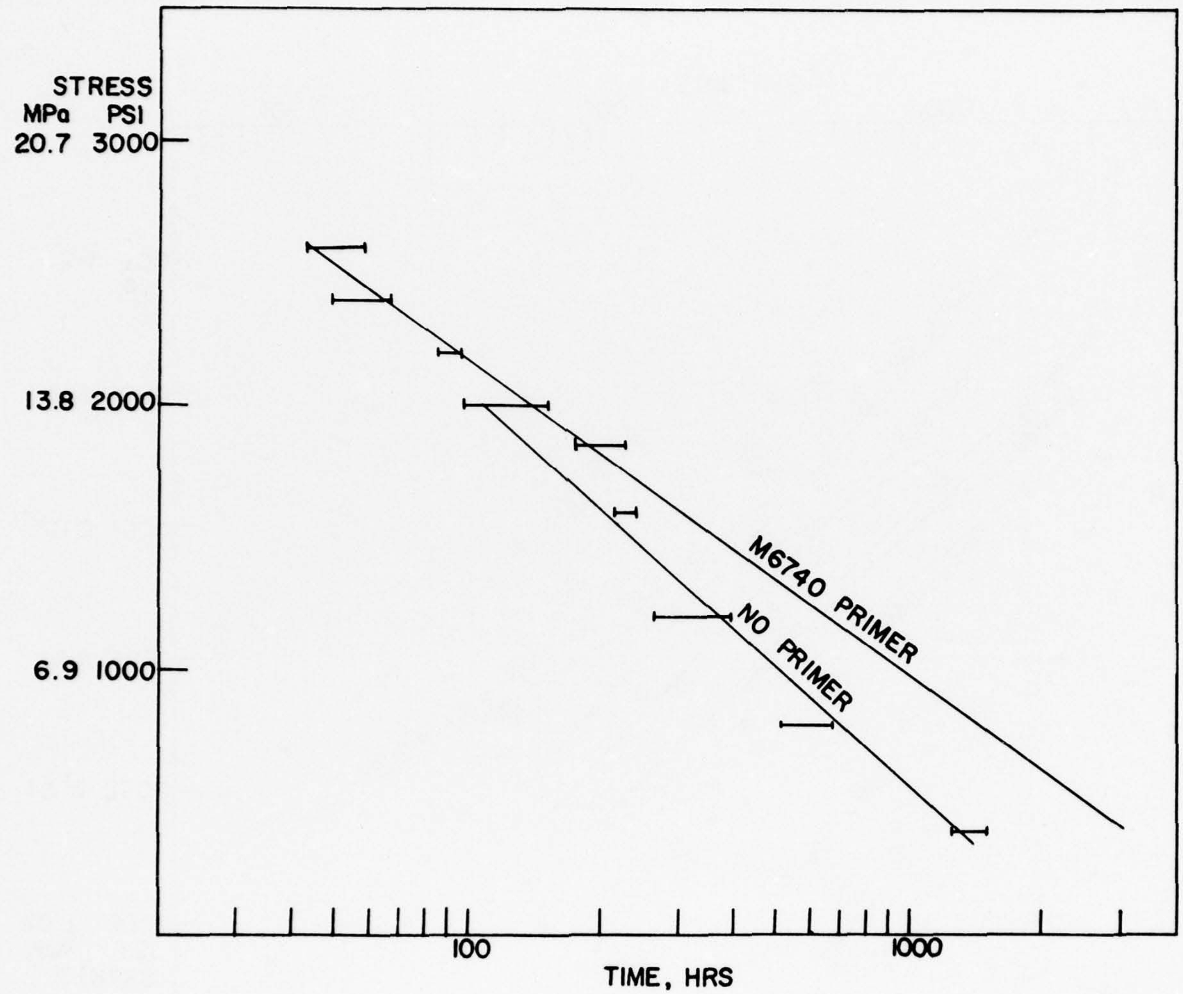


Figure 16. Durability curves for M 1113 with and without M 6040 primer.

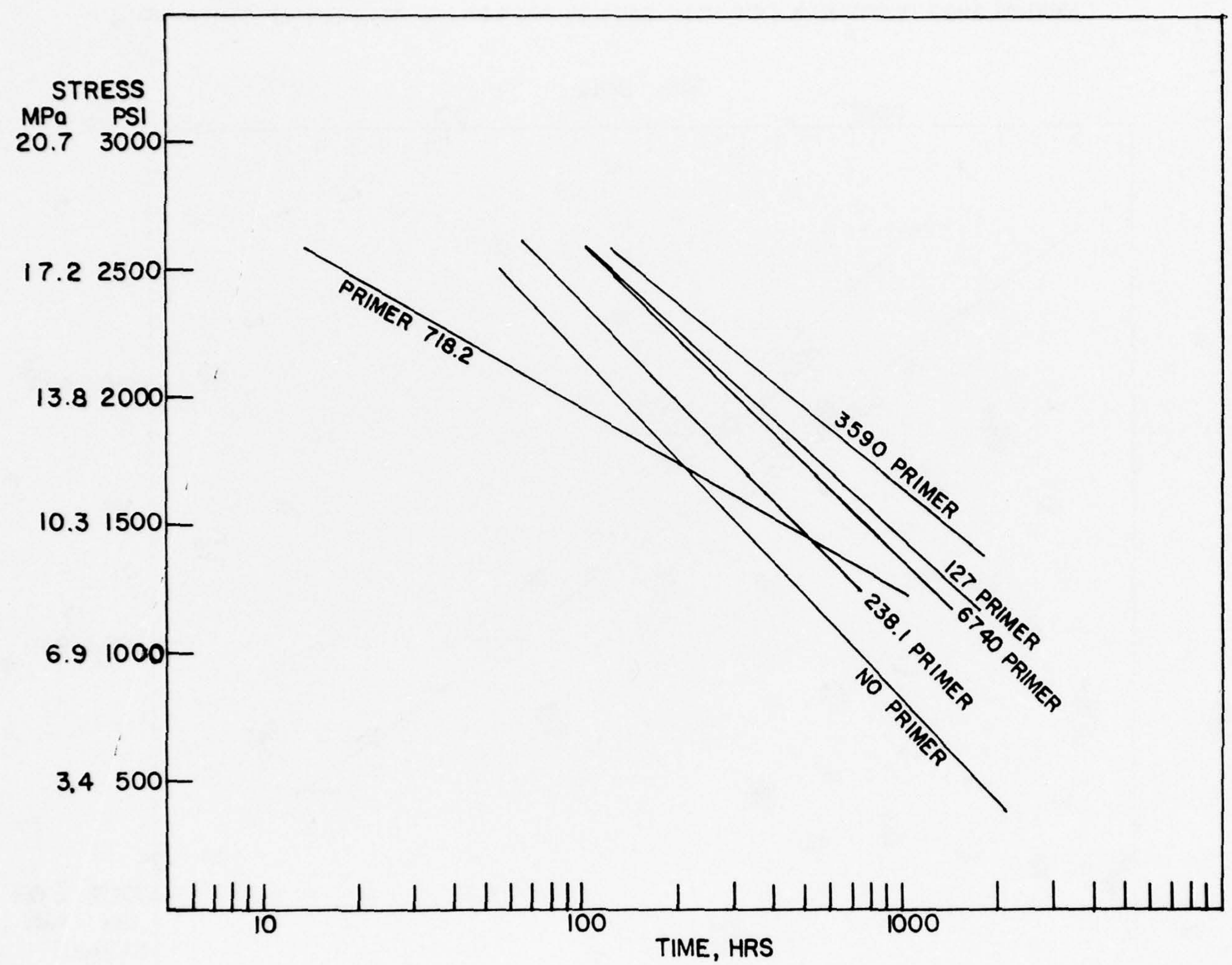
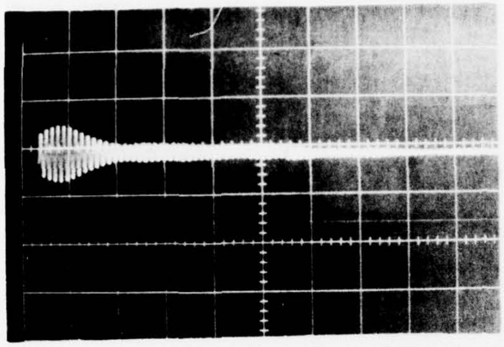
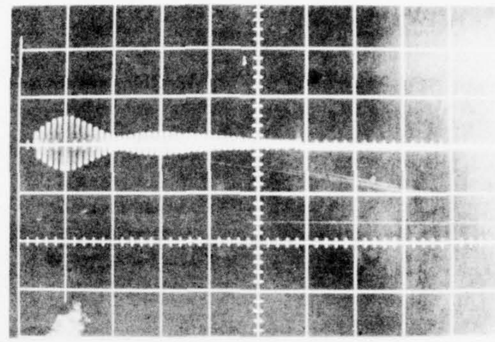


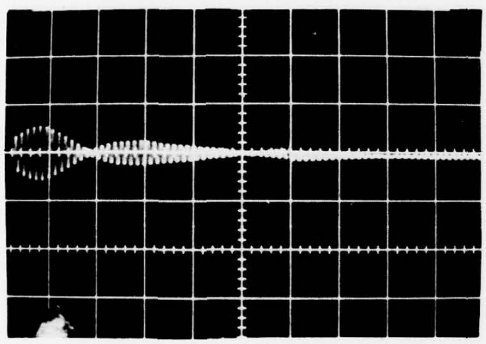
Figure 17. Durability curves comparing joints made with and without corrosion-inhibiting primers.



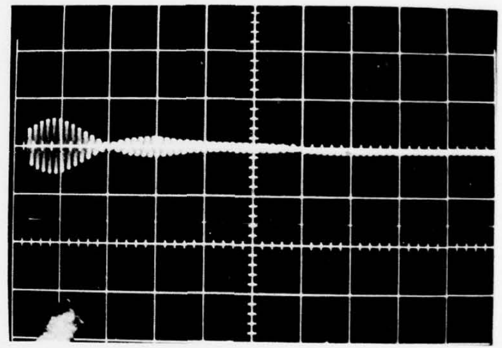
A Unaged panel amplitude 25



B Aged panel 14 days in 60°C water amplitude 26

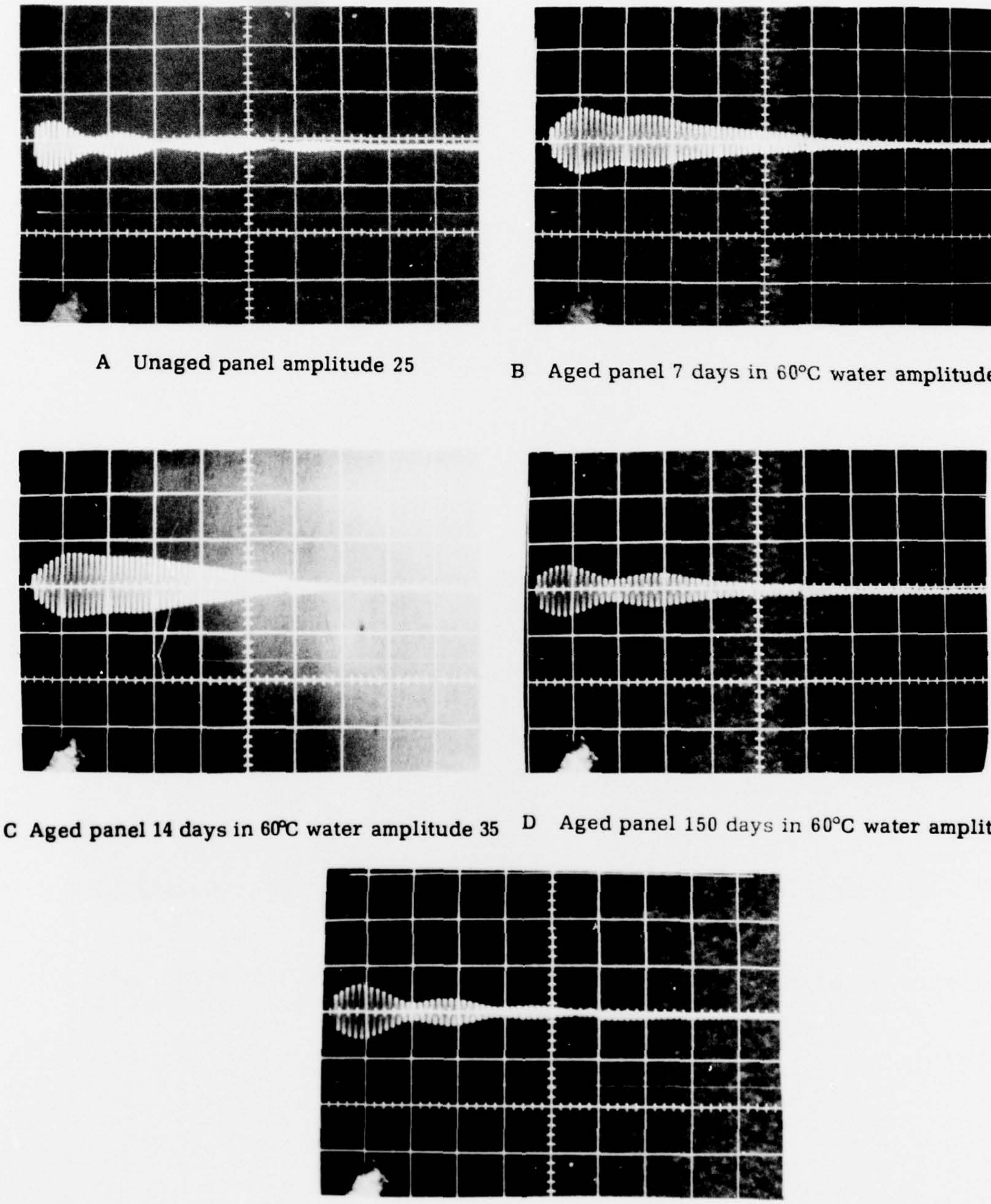


C Aged panel 150 days in 60°C water amplitude 22



D Aged panel 150 days in 60°C water plus 32 days drying amplitude 25

Figure 18. NDI signals obtained from panel bonded with M1113 adhesive.



A Unaged panel amplitude 25

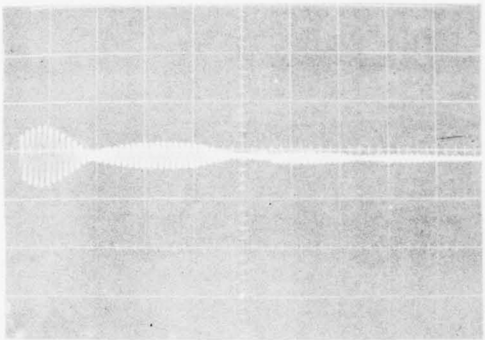
B Aged panel 7 days in 60°C water amplitude 35

C Aged panel 14 days in 60°C water amplitude 35

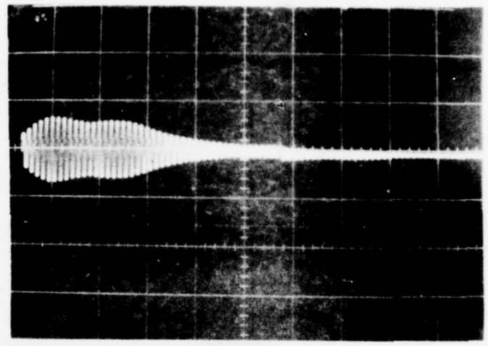
D Aged panel 150 days in 60°C water amplitude 29

E Aged panel 150 days in 60°C water plus 32 days drying amplitude 30

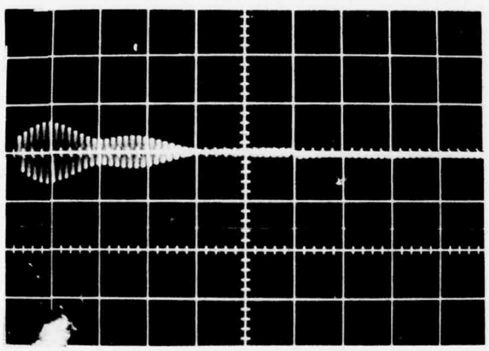
Figure 19. NDI signals obtained from panel bonded with PL717B adhesive.



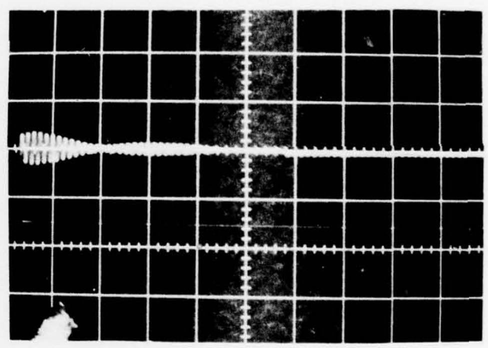
A Unaged panel amplitude 29



B Aged panel 2 days in 60°C water amplitude 33

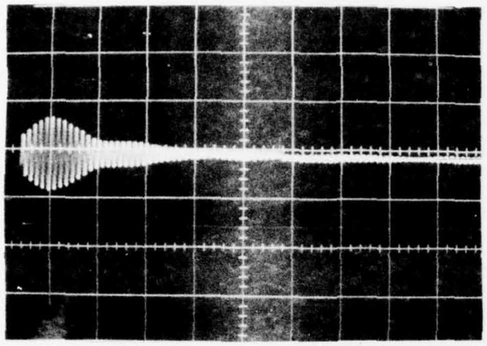


C Aged panel 150 days in 60°C water plus 17 days drying amplitude 28

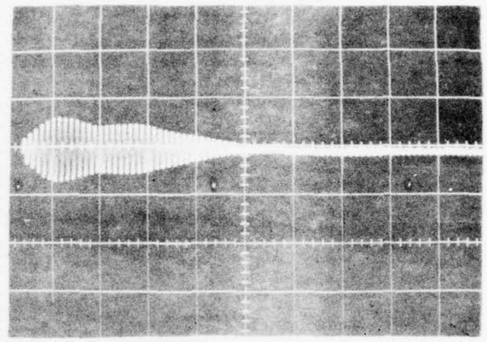


D Aged panel, along edge, 150 days in 60°C water plus 32 days drying amplitude 4

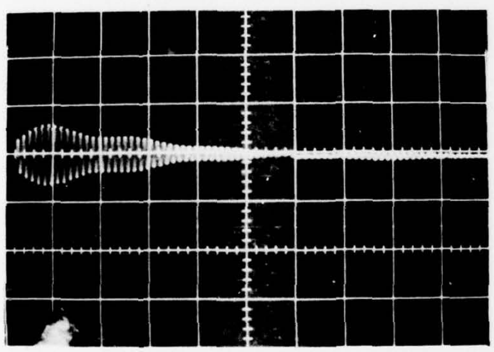
Figure 20. NDI signals obtained from panel bonded with EA 9628 adhesive.



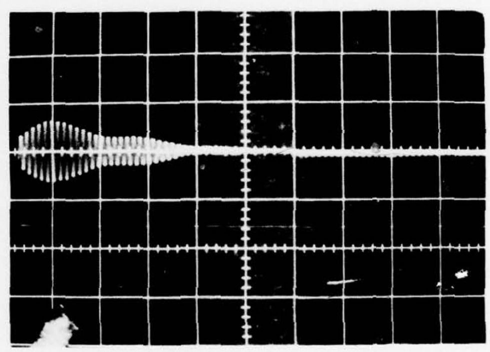
A Unaged panel amplitude 30



B Aged panel 1 day in 60°C water amplitude 34

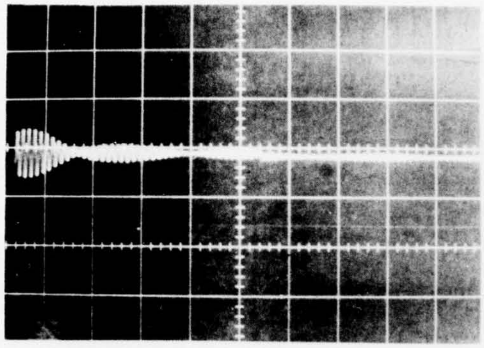


C Aged panel 150 days in 60°C water plus 3 days drying amplitude 25

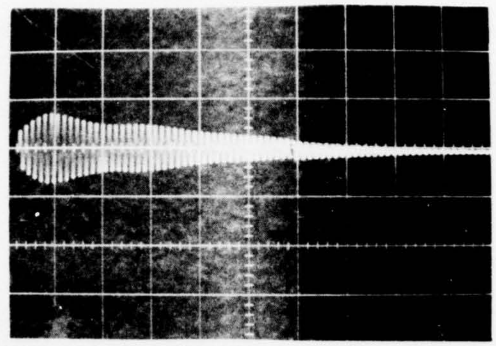


D Aged panel 150 days in 60°C water plus 32 days drying amplitude 25

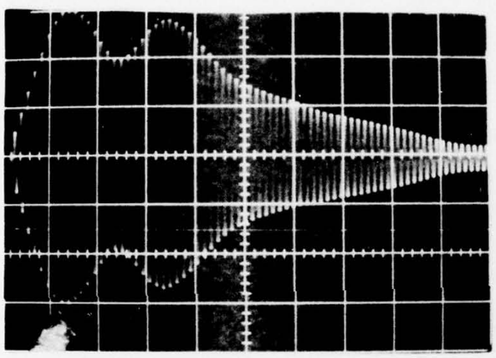
Figure 21. NDI signals obtained from panel bonded with ADX 656.2 adhesive.



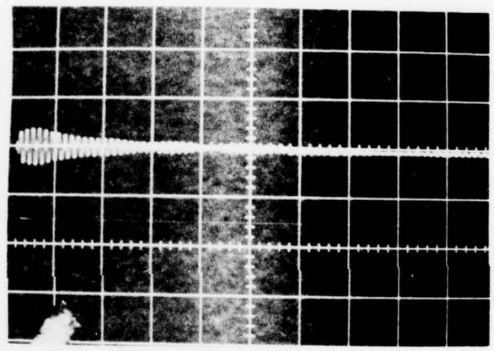
A Unaged panel amplitude 25



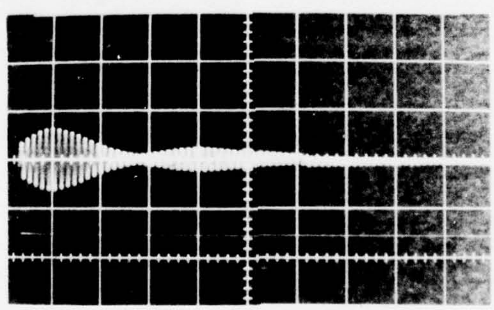
B Aged panel 167 days in 60°C water amplitude 28



C Aged panel, edge, 150 days in 60°C water amplitude 50 plus

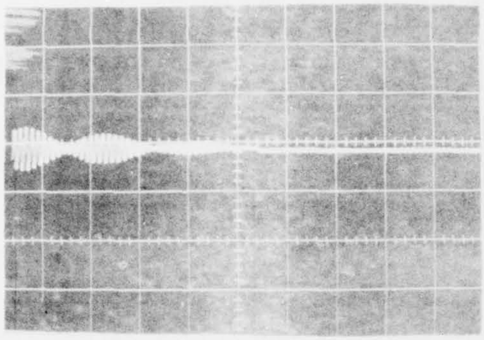


D Aged panel, area preceeding that of view C amplitude 1

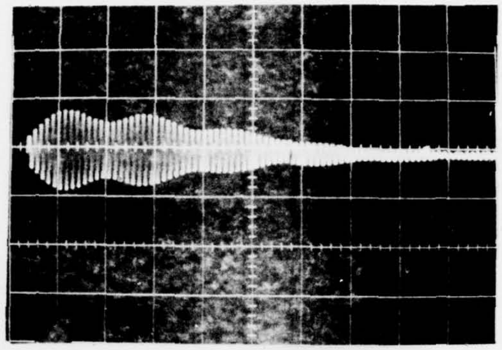


E Aged panel, view D after 32 days drying amplitude 11

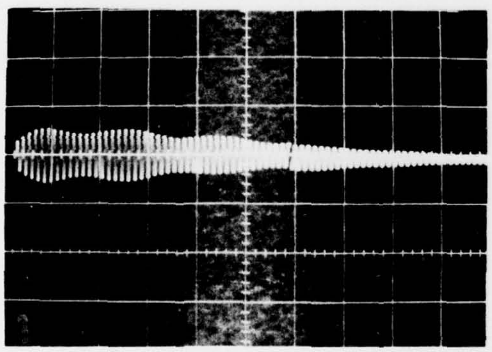
Figure 22. NDI signals obtained from a panel bonded with adhesive A



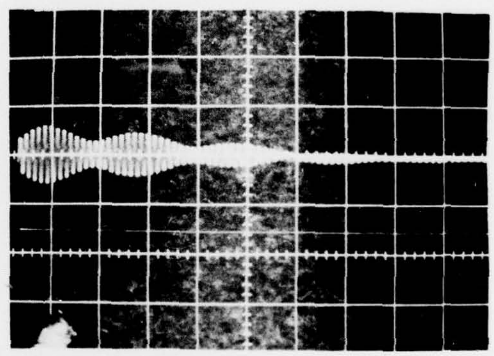
A Unaged panel amplitude 23



B Aged panel 1 day in 60°C water amplitude 26



C Aged panel 67 days in 60°C water amplitude 28



D Aged panel 150 days in 60°C water plus 32 days drying amplitude 25

Figure 23. NDI signals obtained from panel bonded with adhesive B.

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